Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories

Laboratoires de recherche minière

Canada

Canada/NB MDA project on mine-shaft rope testing; testing of 1 1/4 in., FLC, H.R. (our rope #4)

L.B. Geller, D. Poffenroth, J.E. Udd, and D. Hutchinson

MRL report #90-044 (TR) May, 1990

80 pp

MICROMEDIA

91-00388/

CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; TESTING OF $1\frac{1}{4}$ IN., FLC, H.R. (OUR ROPE #4)

by

L.B. Geller*, D. Poffenroth†, J.E. Udd**, and D. Hutchinson††

ABSTRACT

In this report the authors analyse the test-results that were obtained both non-destructively, and destructively, on a $1\frac{1}{4}$ in., 1 × 148, full-locked-coil (FLC) hoist rope. The rope was examined both in situ and on the shop-floor within the context of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. This is the first time a project of this magnitude and diversity has been undertaken.

The results presented here are of particular interest because: (a) the rope in question contained both very good and very bad sections, thus presenting an opportunity to examine both the EM instrument's, and the operator's, capabilities under extreme conditions, (b) in this case we had comparative measurements with three different EM testers in the field, and with five on the shop-floor; three of the latter were, moreover, used at both locations, and (c) the loss-of-metallic-area (LMA) values reported by the operators, both in the field and on the shop-floor, differed widely.

---

* Research Scientist, and ** Director, Mining Research Laboratories, CANMET, Energy Mines and Resources Canada, Ottawa; and † Electronics Engineer, and ††Chief, Industrial and Electrical Safety Division, MSHA, United States Dept. of Labor, Denver.

Keywords: New Brunswick; Mineral Development Agreement; wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Locked-coil ropes

RÉSUMÉ

POJET DE L'EEM CANADA/N.B. SUR L'ESSAI DE CÂBLES POUR PUITS DE MINE; ESSAI DU CÂBLE DE LEVAGE À VERROUILLAGE COMPLET DE $1\frac{1}{4}$ PO (NOTRE CÂBLE #4)

par

L.B. Geller*, D. Poffenroth†, J.E. Udd**, et D. Hutchinson††

Dans le présent rapport, les auteurs analysent les résultats d'essais non destructifs et destructifs sur un câble de levage à verrouillage complet de $1\frac{1}{4}$ po, 1×148. L'analyse du câble de levage a eu lieu in situ et sur le plancher de l'atelier dans le cadre du projet du CANMET visant à effectuer une évaluation comparative du rendement d'une gamme d'appareils d'essai EM. C'est la première fois que l'on entreprend un projet d'une telle envergure et aussi diversifiée.

Les résultats présentés offrent un intérêt particulier pour les raisons suivantes: (a) le câble en question comportait des parties en très bon état et en très mauvais état, donnant ainsi la possibilité d'étudier à la fois les capacités des instruments EM et celles de l'exploitant dans des conditions extrêmes, (b) dans ce cas, nous avons réalisé des mesures comparatives avec trois appareils d'essai EM différents sur le terrain et avec cinq autres sur le plancher de l'atelier; de plus, trois des cinq derniers ont été utilisés aux deux endroits, et (c) les valeurs de la "perte de zone métallique" indiquées par les exploitants, que ce soit sur le terrain ou sur le plancher de l'atelier, ont grandement différé.

---

* Chercheur scientifique et ** Directeur, Laboratoires de Recherche Minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa; et † Ingénieur en électronique, et †† Chef, Industrial and Electrical Safety Division, MSHA, United States Dept. of Labor, Denver.

Mots clés: Nouveau-Brunswick; Entente sur l'exploitation minérale; câbles; essai non destructif; instruments électromagnétiques; câbles à verrouillage complet

CONTENTS

	page No.
ABSTRACT	i
RÉSUMÉ	ii
BACKGROUND	1
ROPE DETAILS	1
IN SITU TEST RESULTS — AS REPORTED	1
IN SITU TEST RESULTS — AS REVIEWED	3
SHOP FLOOR TEST RESULTS — AS REPORTED AND REVIEWED	5
COMPARISON OF IN SITU AND SHOP FLOOR CHARTS	8
DESTRUCTIVE TESTING	11
SUMMARY	13
REFERENCES	14
APPENDIX : Test results; Tables 1 to 4, and Figures 1 to 22	15

BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and its regulators. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, analysed, and clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (1, 2, 3, 4). We are now in the process of reporting the results obtained during the contracted project-phase, which included an extensive series of in situ and shop-floor tests. The first report of this series was published in February, 1990 (5). This is the second such report. Several more are to follow.

ROPE DETAILS

The rope of current interest (referred to as "our rope #4") was designated #3 Head Rope in Denison-Potacan Potash Company's Clover Hill mine at Sussex, New Brunswick. It was used in production shaft #2, and had the reel no. R28-P8391-FH194. It was purchased from Northern Strands (1976) Ltd. on 24.8.84. It measured 32 mm diam × 912 m (2,992 ft). It was of a 1 × 148 FLC construction (37 × 2.74; 64 × 2.49; 22 × 2.25; 12 × 2.46; 6 × 1.14; 6 × 2.79; 1 × 3.12 *mm*), with a mass of 5.93 kg/m (3.98 lb/ft); right-lay outer gallery; galvanized. Its breaking strength was 217,600 lb (Ont. MOL test #65189). It was installed on 15.4.87 and discarded on 20.10.88 (i.e., it was in use for 18 months).

Its predecessor was of identical size and construction, lasting from 11.6.85 to 15.4.87 (22 months). The latter rope's reel no. was R2-P8380-FH184, with a breaking strength of 211,556 lb (Ont. MOL test #65032).

IN SITU TEST RESULTS — AS REPORTED

In situ test results were obtained with the Rotesco AC, the Magnograph, and the LMA-250 instruments.

The 1985-1987 rope was EM tested with a Rotesco AC instrument on 30.9.85 (test #GMP-5); on 26.2.86 (test #MDMP-17); on 8.9.86 (test #DI-MP-20); and on 7.3.87 (test #DMP-12). The respective maximum loss-of-breaking strength (LBS) values were reported to be 3.0%; 3.0% (Fig. 1a); 3.0%; and 5.0% (Fig. 1b), respectively. Strength losses of similar magnitude occurred, consistently, close to (within some 30 ft to 75 ft) both the North and South skips, with the maximums above the North-skip.

The 1987-1988 rope, presently of interest to us, was also tested with a Rotesco AC instrument at regular intervals, along some 2,800 ft. These tests were undertaken on 26.9.87 (test #DMP-54); on 5.3.88 (test #WMP-66); and on 29.9.88 (test #CBMP-9). The maximum LBS values were 1.5% (Fig. 2a); 4.0% (Fig. 2b); and 10.0% (Fig. 2c), respectively. Similar losses were reported at both rope ends, close to (within about 40-60 ft) the North and the South skips, up to March, 1988. However, a significantly increased 10.0% LBS was reported on 29.9.88, some 175-180 ft above the South skip, with only a 5.0% LBS some 90-210 ft above the North skip.

Subsequently, we too had this rope EM tested in situ, on 19.10.88 with the Magnograph, and on 20.10.88 with the LMA-250 instrument. On both occasions service companies, who owned their instruments, undertook the tests for us. The instrument operators were known to, and approved by, the instrument designers/makers. According to the Magnograph operator's report (report #88-525A), a maximum LMA of 10.5% occurred at 2,610-2,700 ft along the 2,826 ft of tested rope-length, i.e., some 126-216 ft from the South skip. It may be noted that on his corresponding LMA charts the operator once marked an 8.0% LMA_{max} (Fig. 3a), and once a 10.0% LMA_{max} (Fig. 3b). At the other rope end, i.e., close to the North skip, the operator reported an LMA of 6.0% (Fig. 3a), equivalent to an LBS of 9.5%, around 156 ft along the chart, and 6.5% LMA (Fig. 3c), equivalent to an LBS of 24.0%, about 240 ft along the chart.

The LMA-250 operator only submitted LMA data. He reported — and marked on his chart (Fig. 4) — a maximum LMA of 23.0%, some 2,290 ft along the 2,540 ft of tested rope length, i.e., some 250 ft from the South skip. At the other, i.e., North skip, rope end he did not mark the observed LMA on his chart. He did, however, show a 3.4% LMA on his chart, around 2,060-2,070 ft along the tested rope length. Note that his first marginal note (at about 45 ft) is in error. His LMA reset here was only 1.0% (not 4.0%).

On reviewing the Rotesco AC, Magnograph, and LMA-250 charts and reports we note that they all agree that the rope is in a fairly good condition along most of its length, except for the two ends close to the skips, with the end close to the South skip in much the worse shape. We also note the major difference (10.5% vs 23.0%) between

the LMA_{max} values reported to us by the LMA-250 and the Magnograph operators. To establish the validity of the data reported by the various operators, we undertook an in-depth chart analysis of our own. It is based, primarily, on a comparative evaluation of the EM test results obtained at the most severely damaged rope sections, i.e., at the two rope ends.

Our conclusions follow.

IN SITU TEST RESULTS — AS REVIEWED

The Rotesco AC data

The Rotesco AC test of 29.9.88 (#CBMP-9) reported an LBS in the order of 5.0% some 90-210 ft above the North skip, and an LBS_{max} of some 10.0% around 175-180 ft above the South skip. According to Rotesco's "Factors — Loss of Strength" (6) the factor for obtaining estimated LBS from measured LMA is 1.59 for a $1\frac{1}{8}$ in., and 1.51 for a $1\frac{3}{8}$ in. rope. A factor of 1.6 is being used by a major Canadian mining company for a $1\frac{5}{16}$ in. rope. The 10.0% LBS, therefore, corresponds to an LMA of some 6.3% - 6.6%. This, and the approximately 5.0% LBS at the other rope end, is confirmed by our review (Fig. 5) of the original Rotesco chart trace (Fig. 2c). For easy comparison we reproduce both charts side-by-side in Fig. 5.

We note the conspicuous LBS_{max} increase in the Rotesco AC reports (from some 4.0% to 10.0%) between March and September, 1988, (i.e., from some 2.5% LMA to 6.3%-6.6% LMA) at the South skip rope end. The corresponding values at the North skip rope end were an LBS increase from some 3.0% to 5.0%, i.e., an LMA increase from some 1.8% to 3.2%.

We suggest that in cases like the present one, with LMA chart readings and LBS estimates more than doubling between consecutive EM tests, it is not safe to let any considerable length of time elapse between field testing and submission of the official report. Rotesco's report of their 5.3.88 test was dated 10.5.88; their report of the 29.9.88 test was dated 1.11.88.

The Magnograph data

The inconsistency of the two LMA_{max} values, as marked by the operator — 8.0% (Fig. 3a) and 10.0% (Fig. 3b) — is an indication of his uncertainty as to the real

LMA value at this, according to him the "South skip", end of his chart. Considering the LMA sensitivity marked on the chart, and its splicing as submitted to us, the 8.0% figure seems to be the correct one, and not the 10.5% reported to us (report #88-525A). However, on realigning and resplicing the contractor's spliced-on chart end (Fig. 3a) correctly, we actually obtain an LMA_{max} value of 13.2% (Fig. 6).

It will be noted that wherever in this report we were unable to reproduce the full length of an instrument-chart in a single stretch (e.g., Figures 3a and 3b) we provided match-marks on the individual chart lengths (such as ref. 'A'; ref. 'B'; etc.)

As to the LBS_{max} value at the, according to the operator "South skip", rope end, we obtained 16.4%, on recalculating the LBS for a 13.2% LMA with the same algorithm as was used by the operator. It will be noted that for the other, according to the operator "North skip", rope end (with a 6.0%-6.5% LMA) the operator's LBS estimate is 9.5% around 156 ft, and 24.0% around 240 ft from the test-start (Fig. 3c). We agree with the operator's 6.0%-6.5% LMA chart reading (Figures 3a and 3c). However, as explained later in this report, we think the operator has: (a) reversed the two rope ends, labelling the South-skip end as the North-skip one, and vice versa, and (b) has spliced to the "South-skip" end of his chart an approximately 300 ft long section which appears to be of questionable relevance. If so, his LMA and LBS data, as well as their locations, are in error.

We shall comment on the LBS calculations in a later report.

The LMA-250 data

The operator of the LMA-250 instrument reported an LMA_{max} of no less than 23.0% some 2,290 ft along the 2,540 ft of tested rope length, i.e., 250 ft from the South skip rope end (Fig. 4). Although the possibility of an almost exponential tendency of rope deterioration, once corrosion has taken hold, is well known, this spectacular LMA_{max} rise from Rotesco's 6.3%-6.6% in September, 1988, to the Magnograph's 8.0%-10.5% in October, 1988, and then, one day later, to the LMA-250's 23.0%, is still very surprising. We described our review of the Magnograph chart in the foregoing. In case of the LMA-250 results, we asked the operator to give us a print-out of his entire original chart length, without any change in the LMA-gain setting — as was seen to have happened at 2,290 ft on the chart we first received (Fig. 4). In reply, we received copies of three partial chart lengths (Fig. 7). We reproduce them in Figures 7a, 7b, and 7c. To make Fig. 7c more easily readable, we realigned and respliced it (Fig. 7d). We also did this to Fig. 4, at its 0-550 ft rope end (Fig. 7e). Thus we obtain (Fig. 7e) a

6.0% LMA value at the "North skip" rope end. Both this value, and the 3.4% LMA in Fig. 7a, are, at first sight, acceptable. But what about the 23.0% LMA chart reading (Figures 4 and 7b)? It is far in excess of the corresponding chart readings, obtained with the Rotesco AC and Magnograph instruments.

Unfortunately, we are unable to resolve the question with any certainty, because the operator was not given the opportunity to undertake a second test run in the field. Also: no calibration wire was taped to the rope during the field measurements. We can, however, make the following observations: (a) in order to prevent the recorder pen from wandering off the LMA chart entirely, the operator had to reset it on numerous occasions, including twice before reaching the questionable 2,290 ft rope section (Fig. 7d): once by some +8.0% (around 2,257 ft) and once by some −2.0% (around 2,262 ft), (b) even so in Fig. 7d he lost the LMA chart record between about 2,248 ft and 2,257 ft, (c) if we ignore whatever additional LMA there may have been in this unrecorded section, we read an LMA of some 16.0% at the worst rope section in Fig. 7d, (d) from Fig. 7b it may be seen that in the unrecorded section there is, in fact, another maximum LMA of about 5.0%, accepting that the LMA gain setting for Fig. 7b is correctly reported at 1.0% per mm (i.e., per small chart-division), (e) on this basis the LMA chart reading (Fig. 7d) at 2,290 ft is −(16.0% + 5.0%), in other words −21.0% which is close to the −23.0% reported on the basis of the spliced chart (Figures 4 and 7b), (f) the spliced, and unspliced, instrument charts are, therefore, in agreement. But did, perhaps, a human error creep into the operator's initial LMA chart marking? We suggest that this may indeed have happened, and that both the unspliced, and spliced, LMA chart sensitivities are less than what they are reported to be. We shall discuss this point in a later report section, after first reviewing the corresponding shop-floor test results as well.

We would also point out that whatever corrosion debris was trapped inside this FLC rope, it did not seem to affect the LMA results of the EM instruments. This confirms our previous conclusions (4), namely that trapped rope-debris has little, if any, effect upon the LMA chart traces.

Details of all test set-ups are listed in Table 1, and results in Tables 2, 3, and 4.

SHOP FLOOR TEST RESULTS — AS REPORTED, AND REVIEWED

General procedure

After the rope of current interest (reel #R28-P8391-FH194) was removed from service on 20.10.88, it was shipped to the plant of Wire Rope Industries Ltd. at Pointe Claire, Quebec. Here it was prepared for shop-floor testing: (a) by winding 2-in. lengths of $\frac{1}{16}$ in. thick seizing wire markings onto it on a 250 ft spacing, and (b) by welding lugs to its ends so that it could be joined, by smaller diam cable lengths, to four other discarded mine-shaft ropes for winding onto a single reel. Our ropes #1, #2, and #3 were joined to the rope of current interest (our #4) on one side, and our rope #5 on the other side. All of these ropes had previously been field tested by us.

Finally, in preparation for shop-floor testing, some 200-250 ft had to be excised from rope #4. This had to be done because a number of wires broke during the rope's dismantling and transport. These were protruding so badly that the rope could not be passed through the EM sensor-heads without seriously endangering their safety. The resulting two rope-lengths — a short one of some 500 ft (our rope #4A), originally at the South skip end of the in situ rope, and a long one of some 1,600-1,800 ft (our rope #4B) — were strung together with a small diam cable, the same way the entire rope-length was joined to four other ropes. It would appear then, that our excised rope length was cut from a section past the badly corroded South skip rope end. The latter was only some 300 ft long (see Figures 2c and 4), while rope section #4A is almost 500 ft long.

The shop-floor tests were undertaken with a Rotesco AC, a Magnograph, a Rotescograph, an LMA-250, and with the prototype version of the latest German WBK instrument. None of the operators knew about each other's results before these were submitted to us. All details of the testing process were described, and illustrated, in our previous shop-floor test report (5).

At this time we have not, as yet, received the German test results. We shall publish these later, as soon as they become available.

The Rotesco AC data

The longer rope length (some 1,600 ft were recorded by the AC tester) was shop-floor tested on 17.3.89 (Fig. 8a). An LMA_{max} of some 3.0% was reported, and a corresponding LBS_{max} of 4.6%. The shorter rope-section could not be tested on this occasion, due to lack of time.

Both rope sections were shop-floor tested on 3.4.89 (Fig. 8b). The seizing wire markers, on a 250 ft spacing, showed up well. In Fig. 8b they are identified by a symbol 'M', while the symbols 'S/V' indicate anomalies due to a 'Speed Variation'. In

the short rope section the LMA_{max} was reported to be 5.4%, and the corresponding LBS_{max} 8.6%. It will be noted that the Rotesco AC tests were undertaken on days when none of the other EM testers (i.e., the ones with strong permanent magnets) were used. This ensured effective rope demagnetization.

Our own analysis of the 3.4.89 Rotesco AC chart trace indicates (Fig. 8c) that, in fact, the LMA_{max} was 7.0% in the short rope section, with a corresponding LBS_{max} of 10.7%. At the other rope end, in the long rope section, we observed an LMA_{max} of 1.8%, with a corresponding LBS_{max} of 2.8%.

The Magnograph data

The entire rope length (of some 505 ft + 1,849 ft) was shop-floor tested on 4.4.89 (Fig. 9a). The seizing wire markers, on a 250 ft spacing, showed up well. In Fig. 9a they are identified by the symbols 'Mk 250 pi', 'Mk 500 pi', etc. In the short rope section the LMA_{max} was reported (report #89-286G) to be 8.5%, with an LMA_{max} of 3.0% at the other rope end. The corresponding LBS_{max} values were reported to be 22.5% some 82-91 ft from test-start, 21.0% some 273-300 ft from test start, and 13.5% some 1,696 ft from test-start, respectively.

Our own review (Fig. 9b) of the 4.4.89 Magnograph chart trace indicates that, in fact, the LMA_{max} in the short rope section was, at least, 11.5%. "At least", because we know that some LMA occurred in the 200-250 ft long excised rope section (originally joining our ropes #4A and #4B) as well. However, from the in situ Magnograph chart (Figures 3a and 3b) it appears that this missing LMA amounted to very little.

We agree that at the other rope end the LMA is 3.0%. Following the same method of calculation as was used by the instrument operator, we find that an LMA_{max} of 11.5% corresponds to an LBS_{max} of 27.8%.

The LMA-250 data

The entire rope length was shop-floor tested on 4.4.89 (Fig. 10). The seizing wire markers, on a 250 ft spacing, showed up well. They are identified by symbols 'M1', 'M2', etc. (Fig 10). In the short rope section the LMA_{max} was reported to be 10.8%. At the other rope end an LMA_{max} of 4.5% was reported. No LBS estimates were provided. We agree with the data reported to us.

The Rotescograph data

The entire rope length was shop-floor tested on 5.4.89, and on 10.4.89. We reproduce the operator's charts (Fig. 11), as submitted to us. Figures 11a and 11b cover the 5.4.89 shop-floor tests, and Figures 11c and 11d those of 10.4.89. The seizing wire markers, on a 250 ft spacing, showed up well. The operator identified them by writing "Marker" on his chart. The operator did not submit a report on his 5.4.89 tests. Nor did he mark up his charts. We added the 100% reference level and the LMA value to Fig. 11b ourselves. As may be seen, though, from the operator's 10.4.89 charts, in this case he did report as follows: (a) an LMA_{max} of 9.0%, some 285 ft from the test-start (Fig. 11c), for the short (500 ft) rope section, and (b) a 1.4% LMA, some 165 ft from test-start (Fig. 11d), for the long (1,840 ft) rope section. The corresponding LBS estimates were always reported at double the respective LMA chart-values.

Our own review (Fig. 12) of the chart traces indicates: (a) an LMA_{max} of 8.3% along the entire rope length (Fig. 12a), and of some 2.4% in the long rope section alone (Fig. 11b), for the 5.4.89 test run, and (b) an LMA_{max} of 4.9% along the entire rope length, and of some 2.7% in the long rope section alone (Fig. 12b), for the 10.4.89 test run. In line with the operator's own calculations, one doubles the respective LMA chart readings to obtain the corresponding LBS estimates.

The 10.4.89 LMA_{max} result (Fig. 12b) is completely out of line with the earlier (5.4.89) Rotescograph chart readings (Fig. 12a). The most likely reason for this discrepancy seems to be some mistake in obtaining the chart-trace for the short rope length. In none of the other rope tests, including both the in situ and shop-floor ones, was such a low LMA_{max} value recorded in this rope section; nor was the best rope section, for setting the 100% reference level, found at this rope end anywhere else.

COMPARISON OF IN SITU AND SHOP FLOOR CHARTS

The Rotesco AC results

As noted before, we had no problem in accepting the operator's in situ test results. However, the shop-floor report was seen to be in error.

In Fig. 13 we juxtapose the field (Fig. 5b) and the shop-floor (Fig. 8c) charts. As may be seen the shapes of the two traces match at the South skip rope end. The corresponding LMA_{max} values also match: -6.9% in the field vs -7.0% on the shop-floor. This is all the more remarkable when one considers that: (a) some six months had elapsed between the two tests, (b) one test was in situ at relatively high rope loading

and speed, and the other on the shop-floor at minimal rope tensioning and speed, and (c) the rope had been roughly handled between the two tests.

Unfortunately, at the other rope end neither the chart shapes, nor the corresponding LMA values (–3.9% vs –1.8%), match equally well. However, at least the more important test results (i.e., for the worst rope section) are in fulll agreement.

The Magnograph results

We pointed out previously the inconsistency in the operator's LMA_{max} chart markings (Figures 3a and 3b), as well as the different LMA_{max} we obtained (Fig. 6) on correctly resplicing the odd chart-end at the operator's "South skip" rope end. We also expressed our view that the operator had, in fact: (a) incorrectly assigned his two rope ends to the "South" and to the "North" skips, and (b) he had spliced on to his chart (Figures 3a and 3b) an approximately 330 ft long section of questionable relevance.

In the latter context we would point out that on comparing, in Fig. 14, the juxtaposed field (Fig. 3b) and shop-floor (Fig. 9b) chart ends there is little doubt that the short (500 ft) rope section #4A, and the operator's "North skip" in situ rope ends are identical. In other words, both charts record the situation at the South skip rope end. This is so: (1) because of the matching LMA traces, and (2) because only the South skip rope end's LF chart-trace has the amplitude and spikiness observed in Figures 3b and 9b. The spikes in the other rope end's LF chart-trace, while also signalling a corroded rope section, are of quite distinctly less amplitude, as can be observed in Figures 4, 9a, 10, and 11a+11b. This is not the case in Figures 3a and 3b.

It follows that the LMA_{max} reading on the in situ Magnograph chart (Figures 3a, 3b, 3c) is, in fact, only 6.0%-6.5%, and that at the other end the spliced-on chart-end should be ignored, thus resulting in an LMA of only some –2.0% at this rope end. The 6.0%-6.5% LMA_{max} actually matches the Rotesco AC chart reading of 6.9%-7.0% (Fig. 5) quite well. At the other rope end the corresponding Rotesco AC and Magnograph LMA values (–3.9% vs –2.0%, respectively) do not match nearly as well. However, the LMA_{max} data are, after all, the most important ones.

We commented earlier on the close match between the Rotesco AC instrument charts, as obtained in the field and on the shop-floor (Fig. 13). We also noted the match between the in situ LMA_{max} chart-readings, as obtained with the Rotesco AC and the Magnograph instruments. Moreover, we illustrated (Fig. 14) the near identity of the Magnograph's LMA charts, as obtained in the field and on the shop-floor. As in the case of the Rotesco AC, the latter result is all the more remarkable because: (a) more than

six months had elapsed between the two tests, (b) one test was in situ at relatively high rope loading and speed, and the other reel-to-reel on the shop-floor, at very low rope tension and speed, (c) the rope had been roughly handled (dismantled, transported, etc.) between the two tests, and (d) it is often said that in situ and reel-to-reel tests are not comparable.

There is, however, a considerable shift in the location of the 100% reference level as found on the in situ (Fig. 3b) and on the shop-floor (Fig. 9b) charts. This results in LMA_{max} readings of 6.5% (Fig. 3c) in the field vs 11.5% (Fig. 9b) on the shop-floor. Interestingly, the latter value matches the 10.8% LMA_{max} obtained with the LMA-250 (Fig. 10) instrument. While the in situ and shop-floor LMA_{max} chart readings with the Magnograph differ greatly, the equivalent LMA-250 and Rotesco AC readings match closely.

We cannot say, with any certainty, why this should be so. With the benefit of hindsight we can, however, say that more care should have been taken to exactly locate and record the position of the damaged rope section, before excising it.

The LMA-250 results

The correctness of the conspicuously large -23.0% LMA_{max}, as recorded in Figures 4 and 7b, has been debated in an earlier report section. Since the operator was, unfortunately not permitted to repeat his test run a second time in the field — and since he did not tape a calibration wire to the rope, as recommended by ourselves and others (5) — we are unable to determine, with certainty, why the in situ LMA-250 chart readings of 20.10.88 should be this far out of line with the in situ Rotesco AC and Magnograph chart-readings. On comparing, though, the LMA-250 operator's in situ test results with the other field results, as well as with all the shop-floor test results, we are of the opinion that a human error occurred in marking the LMA sensitivity on the original, unspliced, instrument chart. We arrived at this conclusion: (a) on comparing all relevant field and shop-floor test results (Tables 2a and 2b), and (b) on examining, in particular, the characteristic "hump" which appears at the South skip rope end on all of these chart-traces, both in the field and the shop-floor (Fig. 15). Surely, its magnitude should be the same on all cogruent chart sections. In fact, this is so for all cases, except the LMA-250 in situ charts (Table 4). It follows that, in actual fact, the %LMA per major chart division on the unspliced LMA-250 chart of 20.10.88 was, probably, set at 0.5%, or even less, rather than at the 1.0% sensitivity marked on the chart. In any case, we reviewed the operator's chart-readings with this in mind. Had there been a calibration wire taped to the rope, this uncertainty would not have arisen.

DESTRUCTIVE TESTING

Five 16-ft samples were cut from our rope #4 for destructive testing. Of these 8-ft samples were used for destructive testing, and 8-ft ones for external and internal visual inspection. Results of the latter work are not available as yet.

To pin-point the location of the desired 16-ft samples, we reran , in March 1990, the rope through the same Magnograph instrument as had been used previously in the field (October, 1988) and on the shop-floor (April, 1989). The same operator ran all tests. As the rope passed through the tester, it was easy to pin-point the desired rope locations by watching the LMA trace and the distance counter. When such a rope location was reached, the reel winder was stopped, and the 16 ft length excised and tagged.

Four of the samples were cut from the 500 ft rope #4A, and the fifth from the 1,849 ft rope #4B. Specifically:

Sample #4a: cut from rope #4B, location '750 pi' (Fig. 9a). It represented the "best" rope section;

Sample #4b: cut from rope #4A, at the interface of ropes #4A and #4B;

Sample #4c: cut from rope #4A, location '349 pi' (Figures 9a and 9b), at the approximate location where the LF signal's amplitude changes from a full-chart width to, more-or-less, the background noise level;

Sample #4d: cut from rope #4A, location '210 pi' (Fig. 9b), at the point of 11.5% LMA_{max}; and

Sample #4e: cut from rope #4A, location '91 pi' (Figures 9a and 9b).

Destructive testing was performed in the laboratories of Wire Rope Industries (WRI) Ltd., at Pointe Claire, Quebec. Standard procedures were followed. The process, and some of the samples, are illustrated in Figures 16-22.

As mentioned before, the original breaking strength of rope #4 was determined by the Rope Testing Laboratory of the Ontario Ministry of Labour, in Toronto. According to their test certificate #65189 it was found to be 217,600 lb. The destructive test results were as follows:

Sample #4a: 224,000 lb, i.e., an increase of 3.0% over the original strength, at a point where the LMA chart reading is 0.0% (Fig. 9a);

Sample #4b: 223,000 lb, i.e., an increase of 2.5% over the original strength, at a point where the LMA chart reading is 3.0% (Fig. 9b);

Sample #4c: 210,000 lb, i.e., a decrease of 3.5% in the original strength, at a point where the LMA chart reading is 5.5% (Fig. 9b);

Sample #4d: 211,000 lb, i.e., a decrease of 3.0% in the original strength, at a point where the LMA chart reading is 11.5% (Fig. 9b), and the LBS_{max} estimates varied from 9.8% to 27.8%;

Sample #4e: 215,000 lb, i.e., a decrease of 1.2% in the original strength, at a point where the LMA chart reading is 9.5% (Fig. 9b).

The original nominal rope diameter was 32 mm (some 1.260 in.) According to WRI's lab. report, all sample diameters were more than this value, ranging from 1.285 in. to 1.300 in.

Although the abovenoted "true" rope breaking strengths are hardly less, and even greater than, the original value, the rope was ready to be discarded. The destructive test results are misleading, insofar as they reflect the work hardened condition of this FLC rope. Consequently, they do not give an accurate picture of the remaining rope life. This phenomenon has been noted, and commented on, especially in case of FLC ropes, in previous CANMET reports (e.g., in ref. 1). Our present results confirm the necessity to measure rope extension, and the rotation resistance of individual wires, as well as the LBS values, in this, and similar cases.

As may be seen in the photographs (Figures 16-22), the condition of the broken samples was as follows:

Sample #4a: all wires broke, except 10 outers, some 4 in. from the cone. This sample had a good appearance visually, with medium surface rusting, and light wear;

Sample #4b: all wires broke, except 8 outers, some 4 in. from the cone. There was medium surface rusting, with medium wear. No defects were either indicated, or visible;

Sample #4c: a complete break was achieved, some 18 in. from the cone. This sample's appearance was the same as that of #4b;

Sample #4d: 13 of the 46 outer wires broke at about the centre of the 8-ft sample. This sample's appearance was the same as that of #4b;

Sample #4e: a complete break was achieved at the cone. This sample's appearance was the same as that of #4b, except that there was an indication of an internal anomaly near the centre of the 8-ft sample.

SUMMARY

We summarized details of the EM test set-ups in Table 1, and the test-results in Tables 2, 3, and 4.

It will be noted that of the reports submitted by three different instrument operators in the field, we could agree only with the Rotesco AC results. Similarly, of the four different instrument operator reports submitted to us after the shop-floor tests, we could again only accept one without alterations, namely the LMA-250 operator's.

As had been pointed out in earlier CANMET reports (3, 5), these problems are of human, and not hardware related origin. Even though, in the present case for example, it had been made abundantly clear that ropes #4A and #4B were two lengths of the same rope, difficulties arose from the fact that rope #4 had been cut into two. It will be noted that at the South skip rope end (Table 2) the overall range of the LMA_{max} chart-readings, even "as reviewed", exceeds the $\pm 2.0\%$ limit we recommend elsewhere (5) as being "acceptable".

In view of the inconsistency of the present results (Tables 2 and 3), we are unable to say, with any certainty, whether, or not, the in situ and reel-to-reel LMA_{max} chart-readings are comparable. The Rotesco AC and LMA-250 quantitative results, as well as the near identity of the Magnograph's in situ and shop-floor instrument charts (Fig. 14), indicate that they are so. This is contrary to what has, on occasion, been said elsewhere. We suggest, however, that our contention needs to be viewed in the following context: (a) the %LMA chart-readings are not absolute, but relative ones, say of the "worst" in relation to the "best" rope section; but (b) how much does this ratio between "worst" and "best" change from when a rope is in situ, to when it is on the shop-floor?

We also spoke before about the importance of checking for "repeatability" (5). In this respect we point to Figures 14 and 15 in the present report. It is quite remarkable how accurately the in situ and shop-floor instrument charts of the Magnograph (Fig. 14) match each other, even though they were obtained some six months apart, at two entirely different locations. It is equally remarkable how the characteristic rope anomaly at the South skip rope end (Fig. 15) is reproduced on a number of EM charts, obtained many months apart, at different locations, with different instruments, and by different operators who worked quite independently of each other.

As for the destructive test results: the "true" LBS results were found to be misleading, insofar as they reflected the work hardened condition of this FLC rope. Therefore, they did not give an accurate picture of the remaining rope life. This is a phenomenon that has been pointed out, especially in case of FLC ropes, in previous CANMET reports (e.g., in ref. 1). We feel confident, therefore, that had the rope extension and the rotation resistance of individual wires been obtained, this situation would have been fully documented. In any case, the EM test results on their own provided ample evidence of the need to discard this rope, even if the destructive test results did not support the corresponding LBS estimates.

REFERENCES

1. Geller, L.B.; Udd, J.E.; and Mitchell, E.W. "Comparative evaluation of mine-shaft wire-rope NDT instruments: a search for, and analysis of, background information — contribution to the Canada/USBM/Ontario MOL joint R&D program"; CANMET Division Report MRL 88-78, 139 pp; July, 1988.

2. Geller, L.B.; Anderson, G.L.; Miscoe, A.J.; and Mitchell, E.W. "The safety of mine-shaft wire-ropes — cooperative work by Canada and the U.S.A."; CANMET Division Report MRL 89-14, 28 pp; February, 1989.

3. Geller, L.B.; Udd, J.E.; Blanchard, R.; and Daniel, K.E. "About electro-magnetic wire-rope testing in New Brunswick mines, and related data"; CANMET Division Report MRL 89-40, 51 pp; October, 1989.

4. Geller, L.B.; and Rousseau, G. "Effect of trapped wire-rope debris upon an EM instrument's LMA chart-trace"; CANMET Division Report MRL 90-08, 29 pp; February, 1990.

5. Geller, L.B.; Rousseau, G.; and Poffenroth, D. "Canada/NB MDA project on mine-shaft rope testing; stranded ropes with artificial defects"; CANMET Division Report MRL 90-15, 117 pp; February, 1990.

6. Rotesco AC "Operating manual"; 21 pp;

APPENDIX

Tables 1, 2, 3, and 4

as well as Figures 1 to 22, inclusive

Table 1

Details of EM testing of the 1 1/4 in FLC rope

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*
1	Rotesco AC	DMP-54	26.9.87	in situ	(1)
2	Rotesco AC	WMP-66	5.3.88	in situ	(1)
3	Rotesco AC	CBMP-9	29.9.88	in situ	(1)
4	Magnograph	88-525A	19.10.88	in situ	(2)
5	LMA-250		20.10.88	in situ	(3)
6	Rotesco AC		17.3.89	shop-floor	(4)
7	Rotesco AC		3.4.89	shop-floor	(4)
8	Magnograph	89-286C	4.4.89	shop-floor	(2)
9	LMA-250		4.4.89	shop-floor	(5)
10	Rotescograph		5.4.89	shop-floor	(6)
11	Rotescograph		10.4.89	shop-floor	(6)

*: (1) and (3) instr. maker and service company

(2) service company

(4) and (6) mining company

(5) government organisation

Table 2a

LMA_{max} chart readings, and LBS_{max} estimates —
South skip rope end; in situ tests

Item No.	Test Instr.	As reported		As reviewed	
		LMA_{max}	LBS_{max}	LMA_{max}	LBS_{max}
1	Rotesco AC	0.9%	1.5%	0.9%	1.5%
2	Rotesco AC	2.5%	4.0%	2.6%	4.0%
3	Rotesco AC	6.3%	10.0%	6.9%	10.0%
4	Magnograph	8.0; 10.0% 10.5%		6.0; 6.5%	9.5; 24.0%
5	LMA-250	23.0%		11.5%	

Table 2b

LMA_{max} chart readings, and LBS_{max} estimates —
South skip rope end*; shop-floor tests

Item No.	Test Instr.	As reported		As reviewed	
		LMA_{max}	LBS_{max}	LMA_{max}	LBS_{max}
7	Rotesco AC	5.4%	8.6%	7.0%	10.7%
8	Magnograph	8.5%	22.5; 21.0%	11.5%**	27.8%
9	LMA-250	10.8%		10.8%	
10	Rotescograph	—	—	8.3%	16.6%
11	Rotescograph	9.0%	18.0%	4.9%	9.8%

*: rope #4A on shop-floor

**: at least

Table 3a

LMA_{max} chart readings, and LBS_{max} estimates — North skip rope end; in situ tests

Item No.	Test Instr.	As reported		As reviewed	
		LMA_{max}	LBS_{max}	LMA_{max}	LBS_{max}
1	Rotesco AC	0.9%	1.5%	0.9%	1.5%
2	Rotesco AC	1.8%	3.0%	1.8%	3.0%
3	Rotesco AC	3.2%	5.0%	3.9%	5.0%
4	Magnograph	6.0; 6.5%	9.5; 24.0%	2.0%	
5	LMA-250	6.0%		3.0%	

Table 3b

LMA_{max} chart readings, and LBS_{max} estimates — North skip rope end*; shop-floor tests

Item No.	Test Instr.	As reported		As reviewed	
		LMA_{max}	LBS_{max}	LMA_{max}	LBS_{max}
6	Rotesco AC	3.0%	4.6%	2.4%	3.7%
7	Rotesco AC	—	—	1.8%	2.8%
8	Magnograph	3.0%	13.5%	3.0%	13.5%
9	LMA-250	4.5%		4.5%	
10	Rotescograph	—	—	2.4%	4.8%
11	Rotescograph	1.4%	2.8%	2.7%	5.4%

*: rope #4B on shop-floor

Table 4

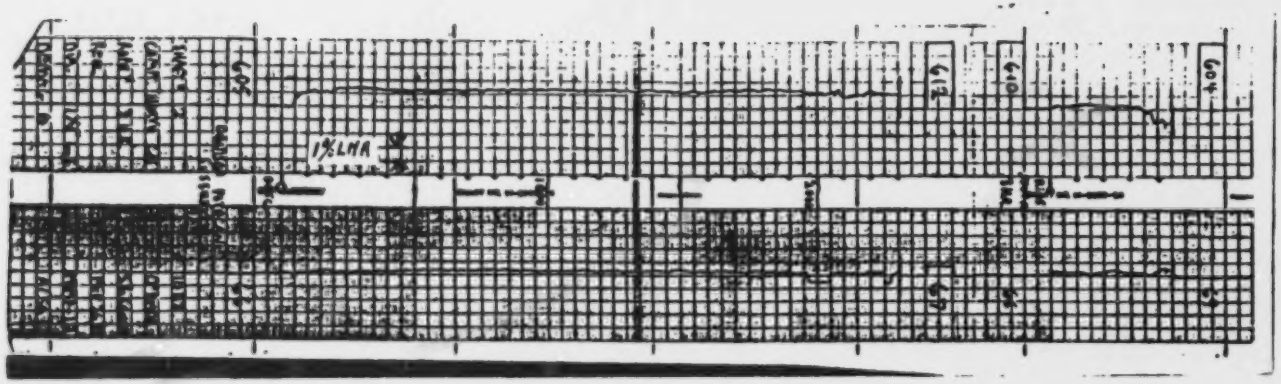
Characteristics of "hump" at South skip rope end

Item No.	Test Instr.	Fig. No.	Test date	Test location	Instr. operator*	'L'** (ft)	'X'** (LMA%)
5	LMA-250	7d	20.10.88	in situ	(3)	45.8	7.0
5	LMA-250	7b	20.10.88	in situ	(3)	46.7	7.0
9	LMA-250	10	4.4.89	shop-floor	(5)	44.4	2.2
4	Magnograph	3b	19.10.88	in situ	(2)	50.4	2.4
8	Magnograph	9a	4.4.89	shop-floor	(2)	48.0	2.5
10	Rotescograph	2a	5.4.89	shop-floor	(6)	43.6	2.2

*: see Table 1 for these symbols

**: see Fig. 15 for these symbols

(a)



(b)

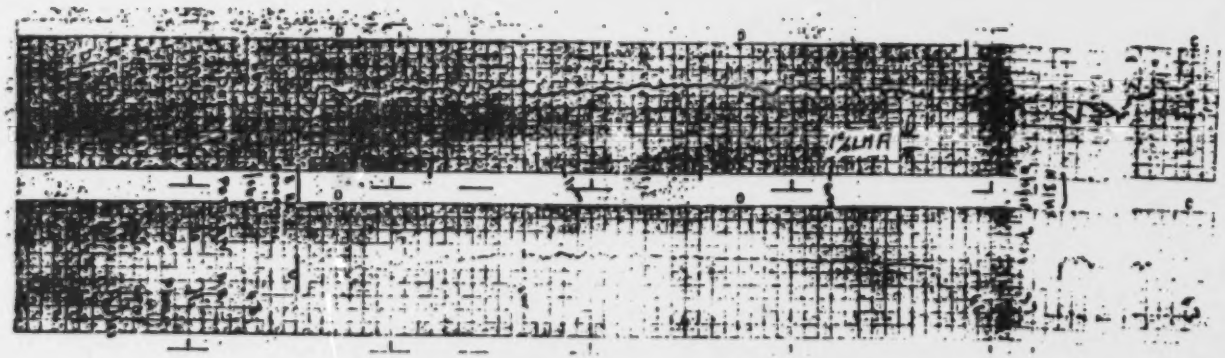


Fig. 1 — Rotesco AC in situ tests of 1985-1987 rope; (a) test #MDMP-17 of 26.2.86, (b) test #DMP-12 of 7.3.87

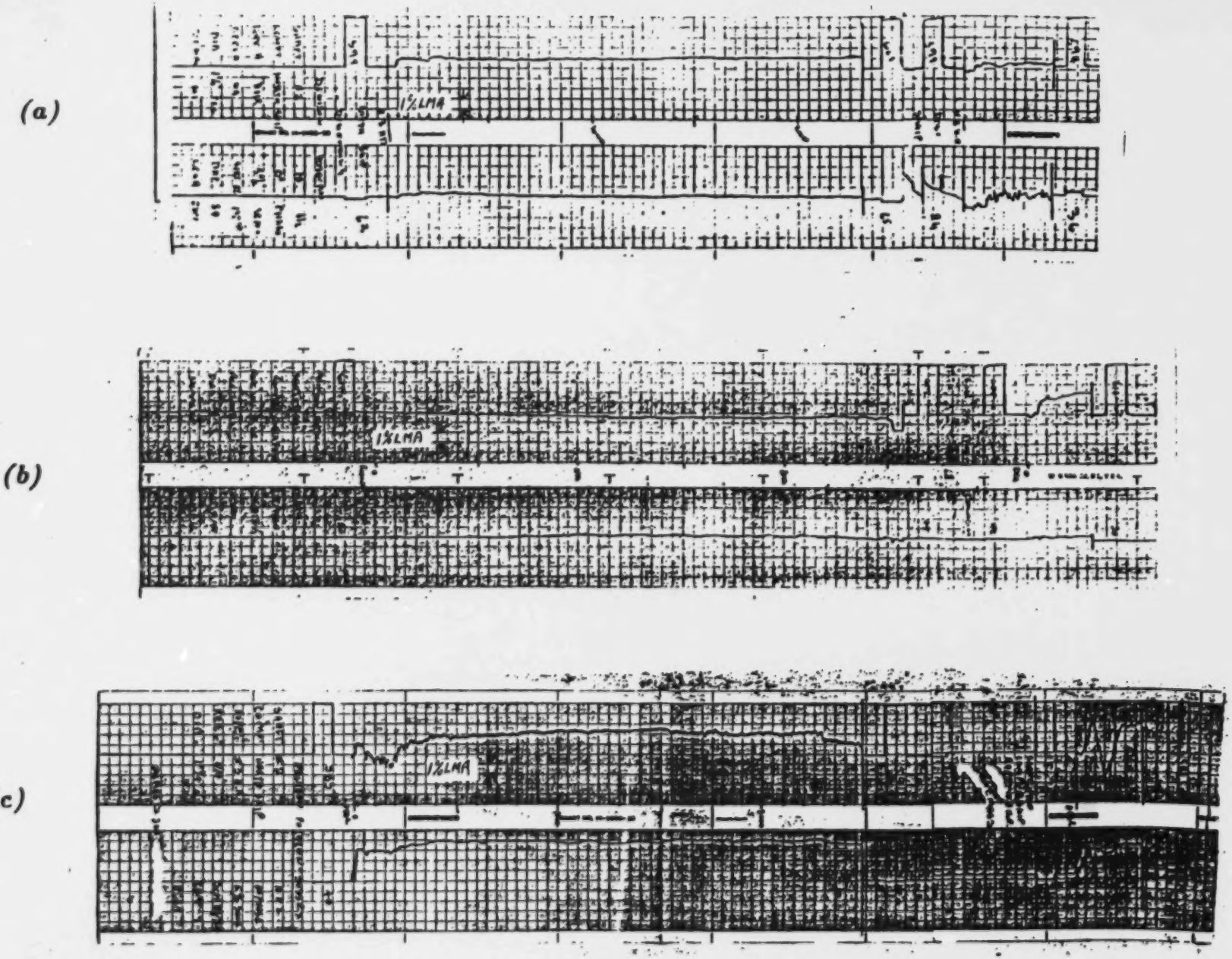


Fig. 2 — Rotesco AC in situ tests of 1987-1988 rope; (a) test #DMP-54 of 20.9.87, (b) test #WMP-66 of 5.3.88, (c) test #CBMP-9 of 29.9.88

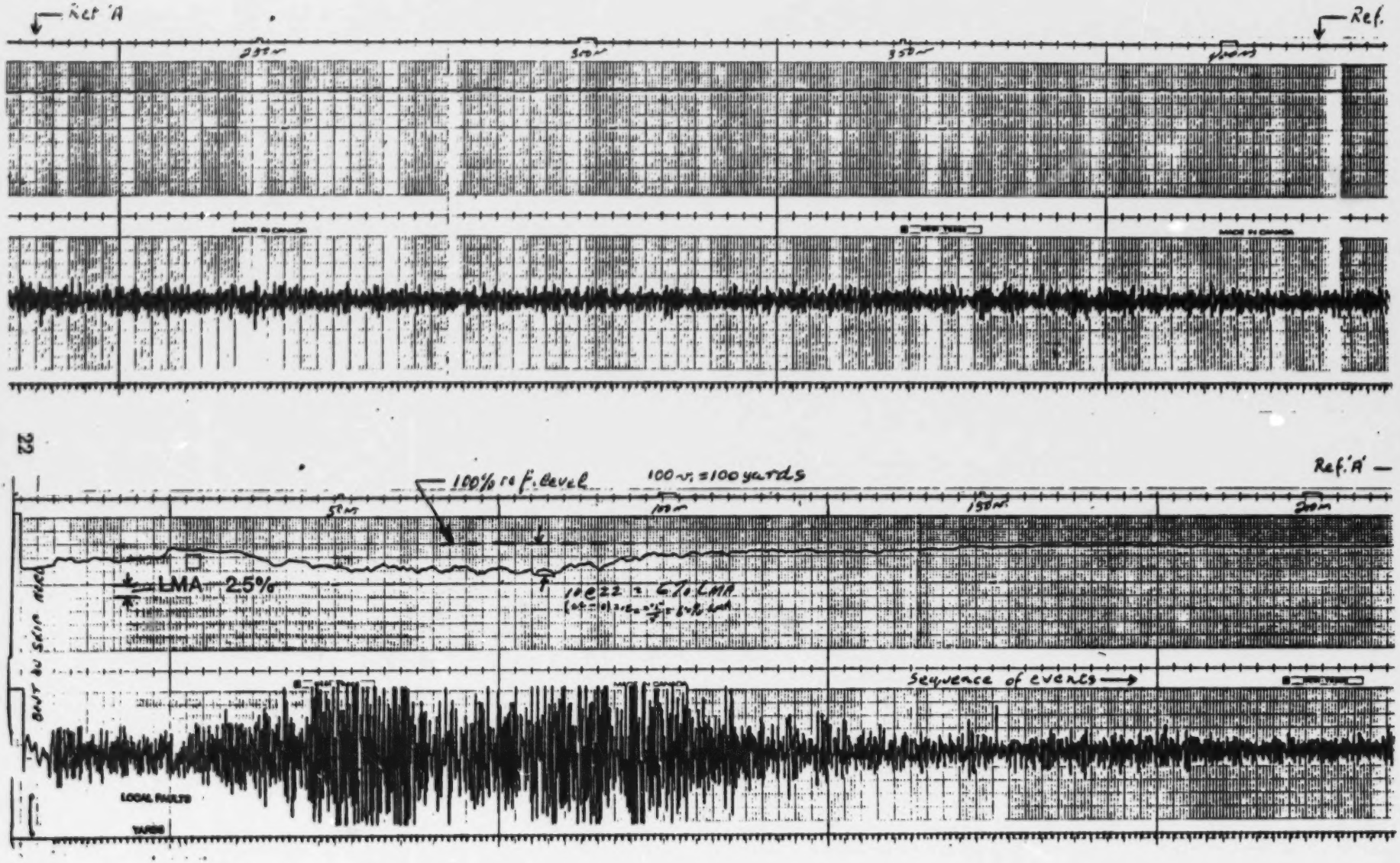


Fig. 3a — Magnograph in situ test of 1987-1988 rope; test #99-525A of 19.10.88 (max LMA=8.0%)

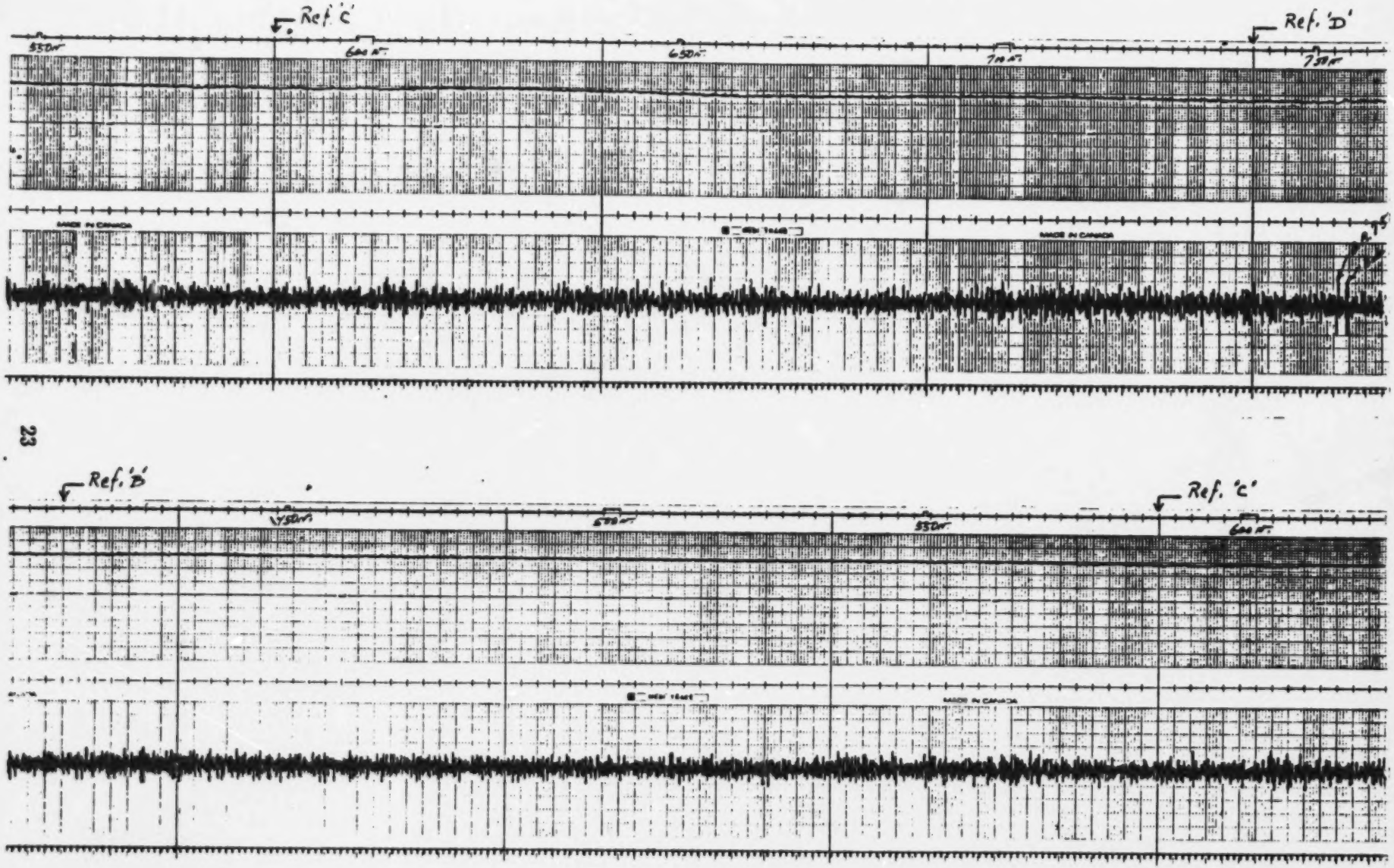


Fig. 3a (continued) — Magnograph in situ test of 1987-1988 rope; test #99-525A of 19.10.88 (max LMA=8.0%)

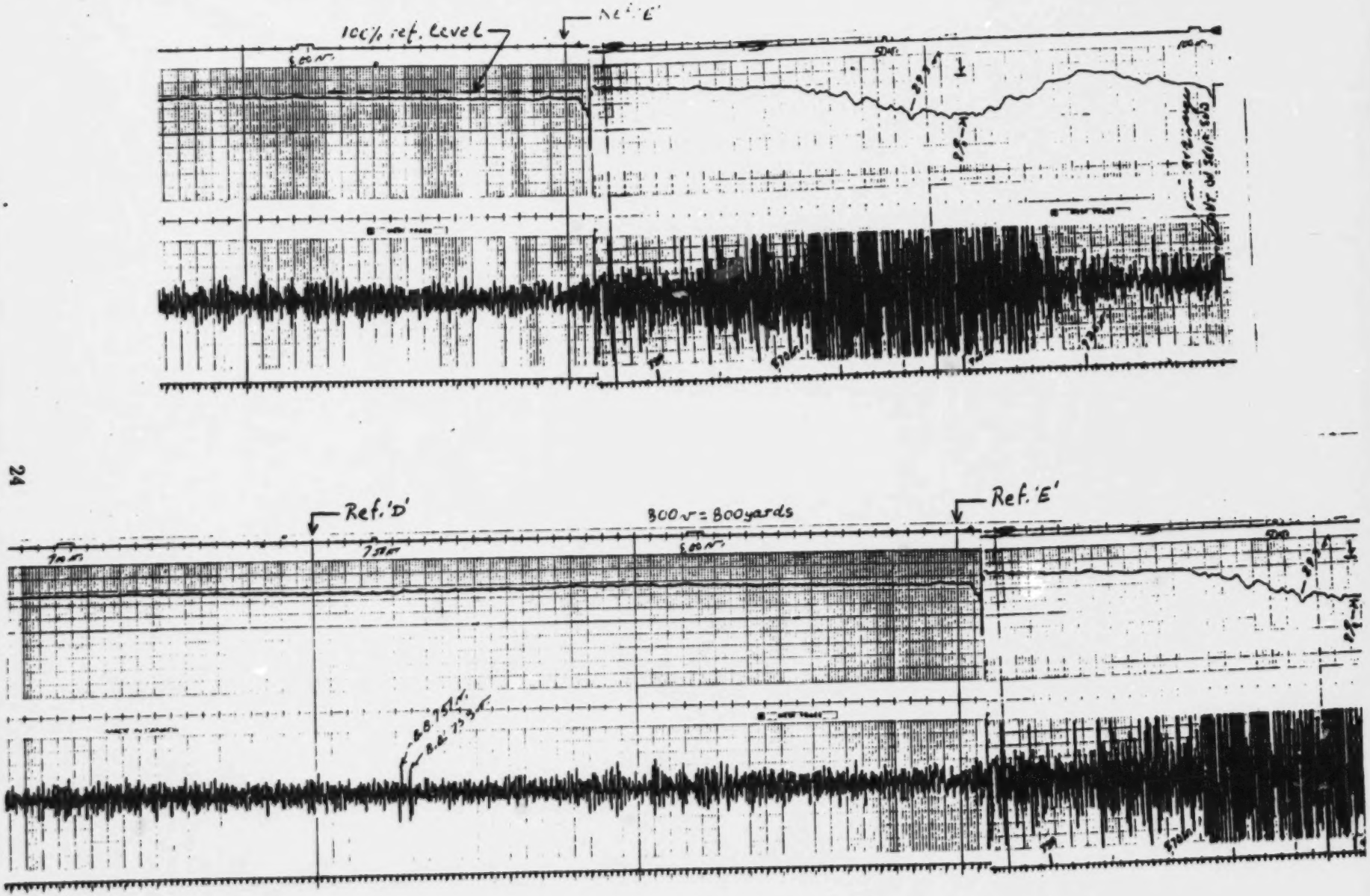


Fig. 3a (continued) — Magnograph in situ test of 1987-1988 rope; test #99-525A of 10.10.88 (max LMA=8.0%)

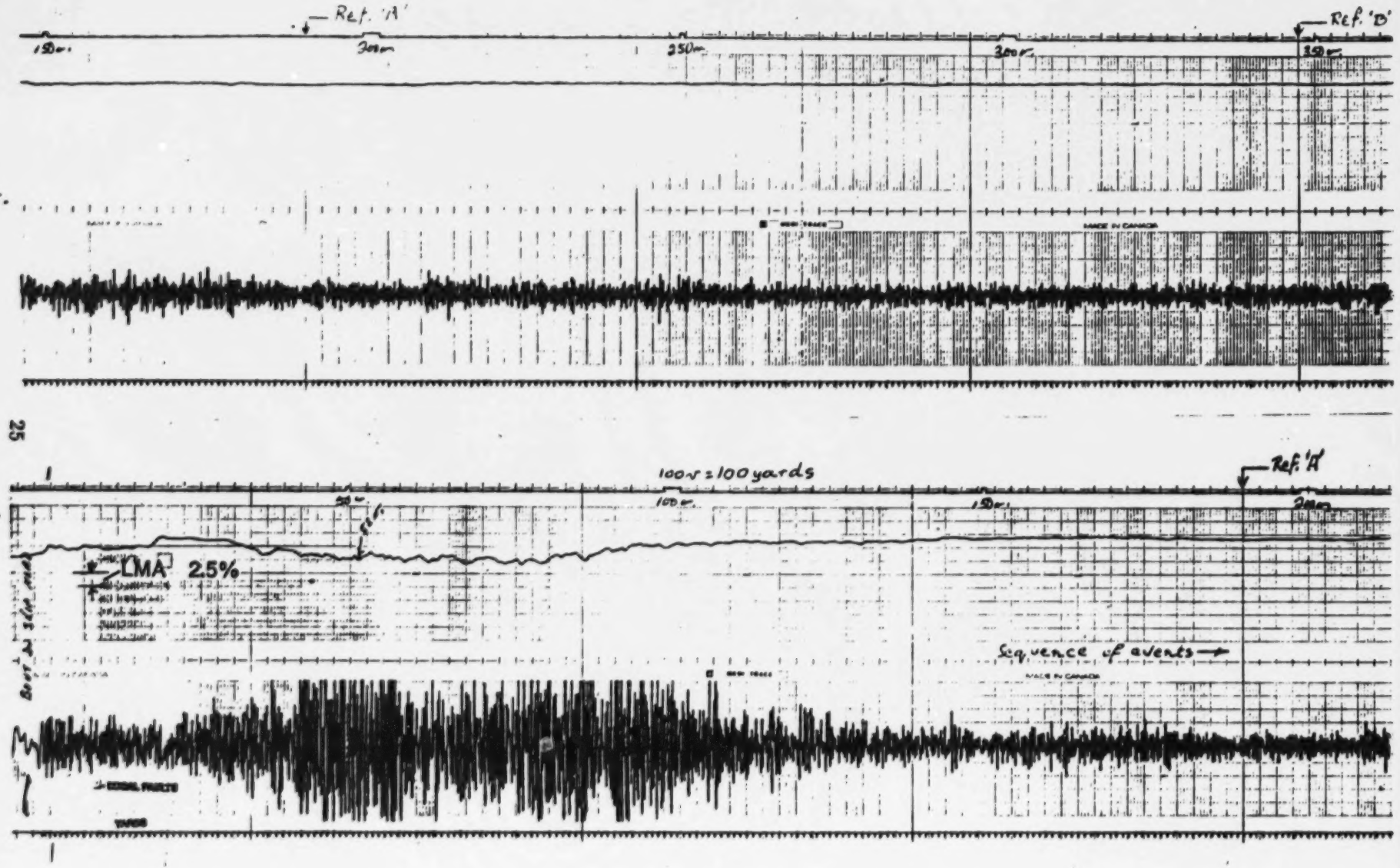


Fig. 3b — Magnograph in situ test of 1987-1988 rope; as Fig. 3a, but with max LMA=10.0% marking

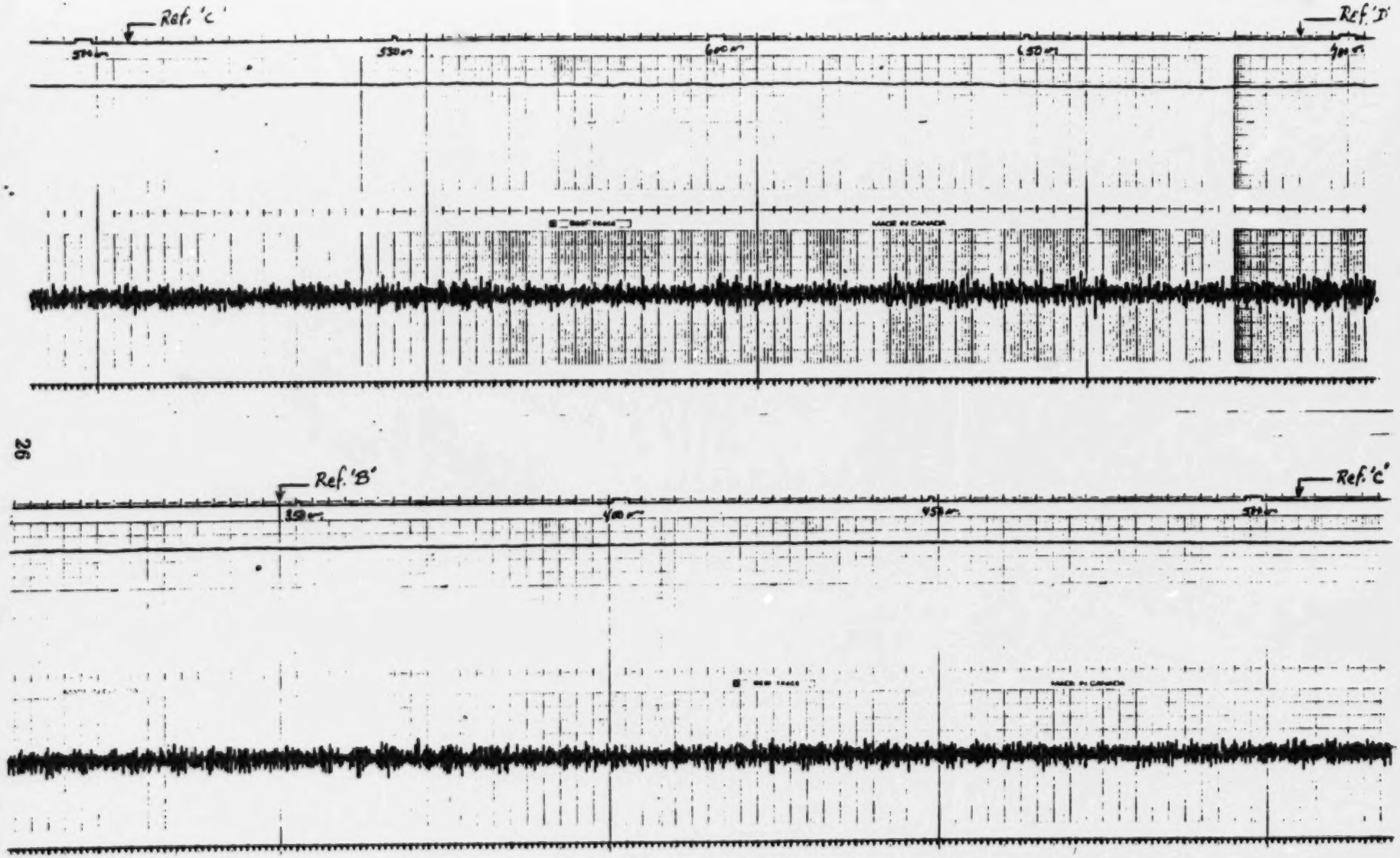


Fig. 3b (continued) — Magnograph in situ test of 1987-1988 rope; as Fig. 3a, but with max LMA=10.0% marking

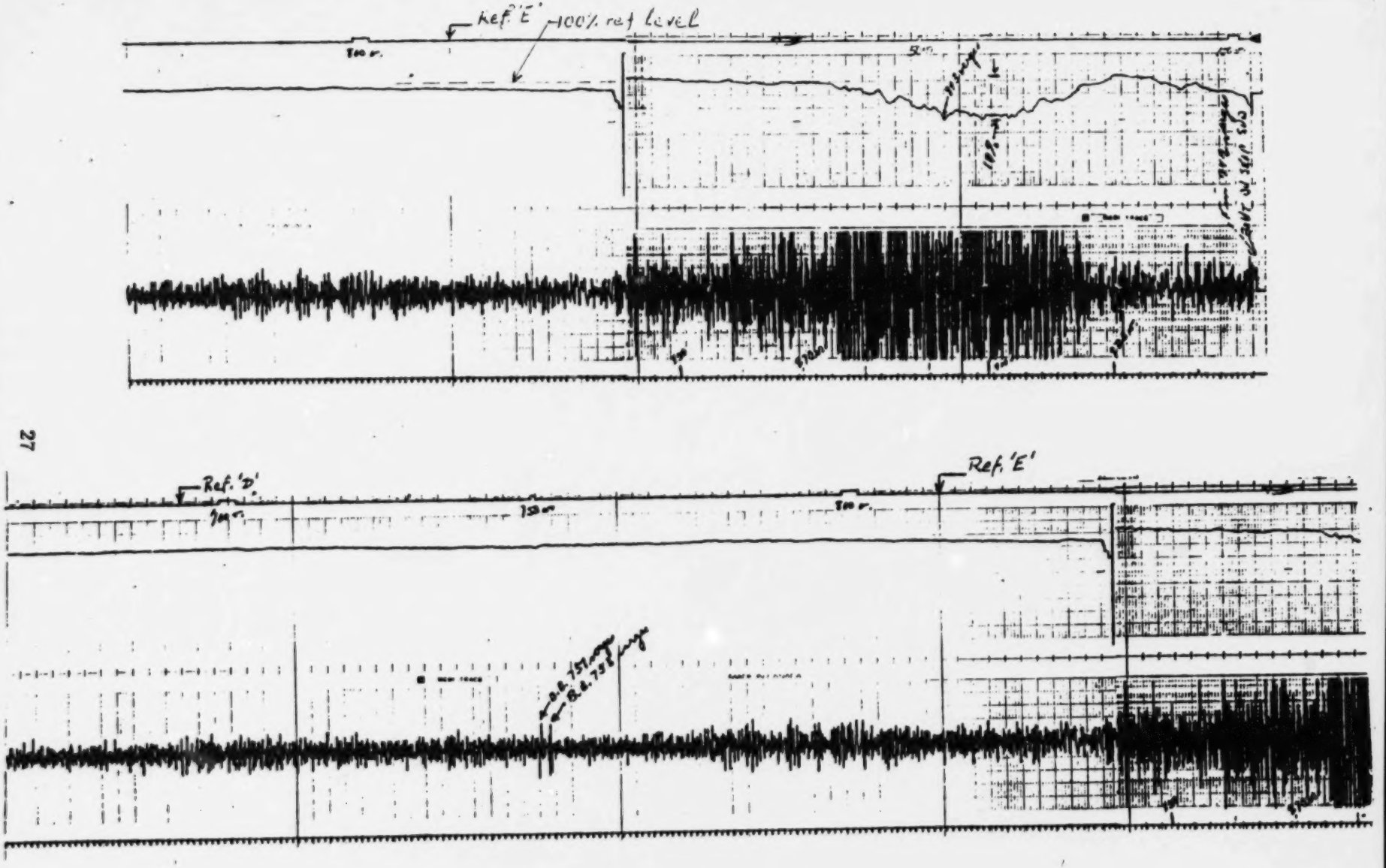


Fig. 3b (continued) — Magnograph in situ test of 1987-1988 rope; as Fig. 3a, but with max LMA=10.0% marking

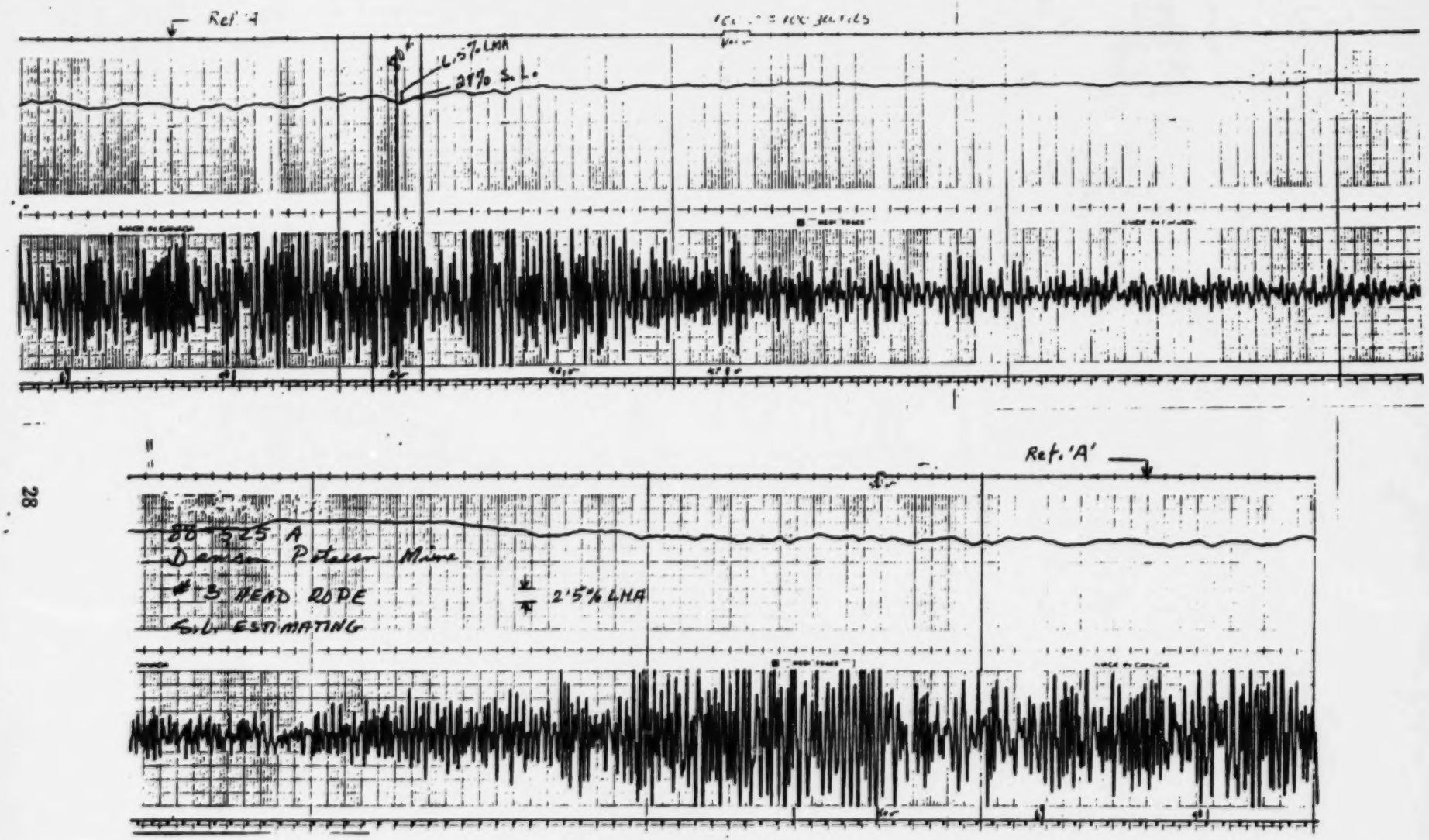


Fig. 3c — Magnograph in situ test of 1987-1986 rope; as Fig. 3a, but with increased chart speed, to permit LBS calculation

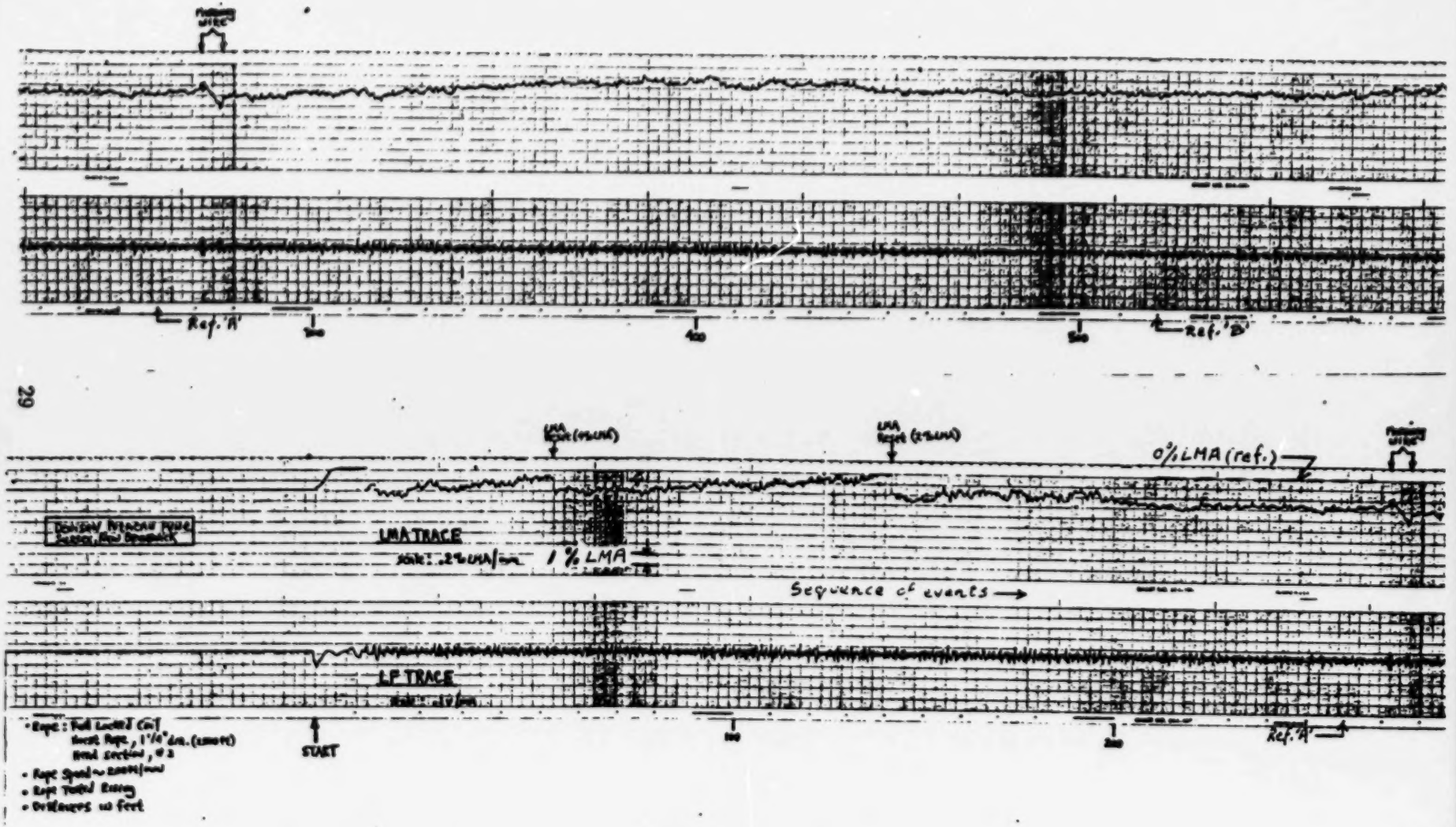


Fig. 4 — 20.10.88, LMA-250 in situ test of 1987-1988 rope

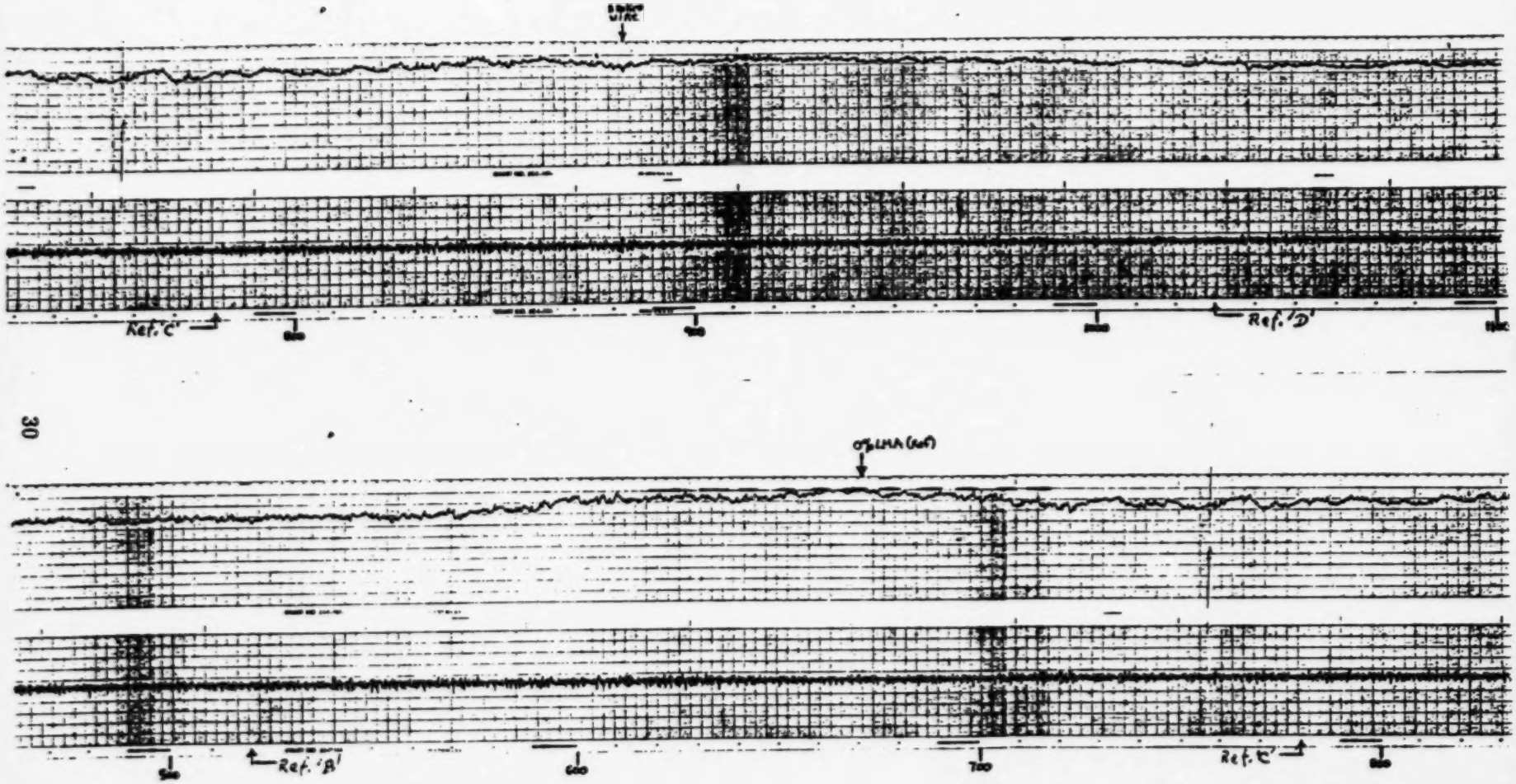


Fig. 4 (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope

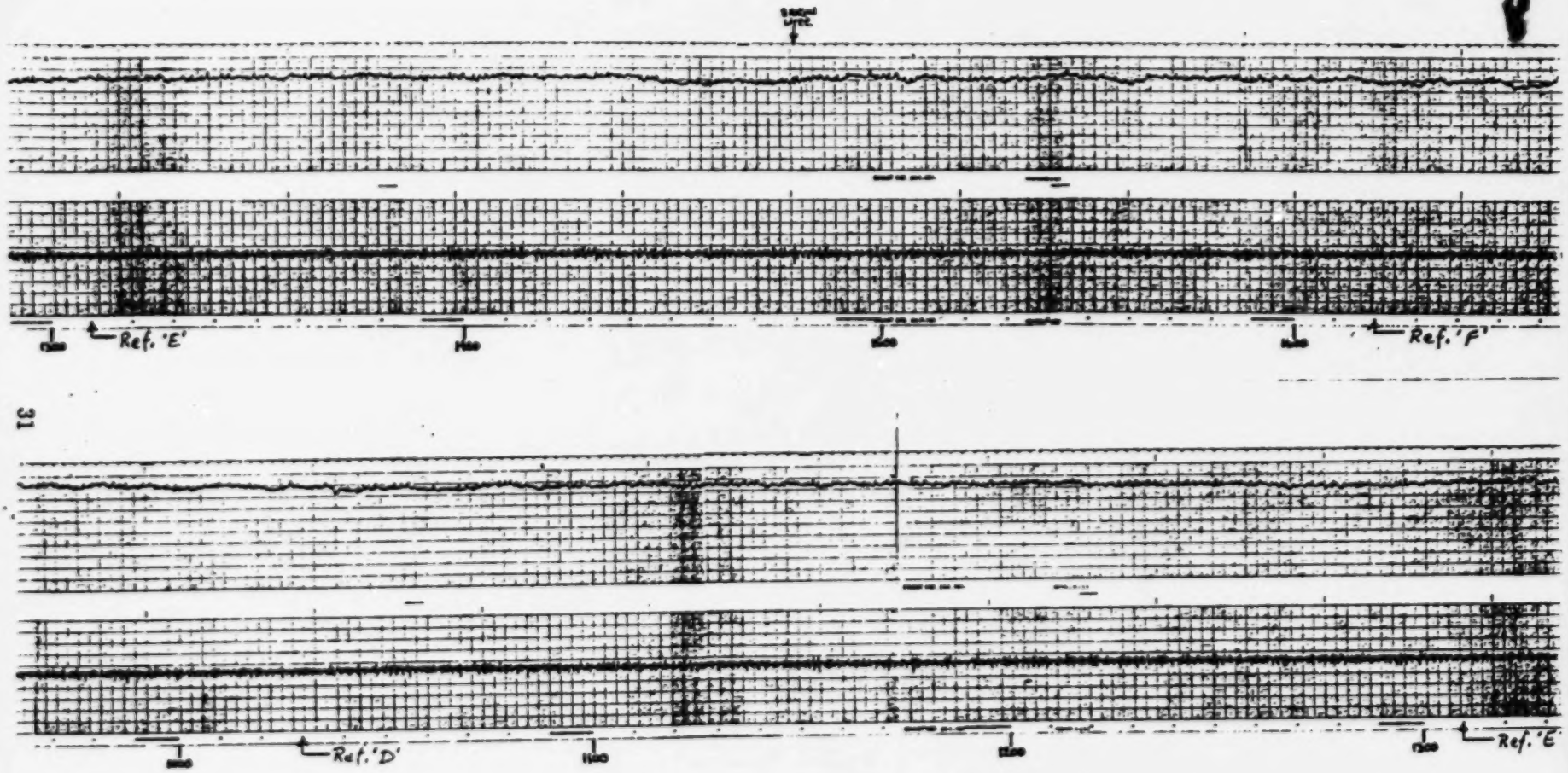


Fig. 4 (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope

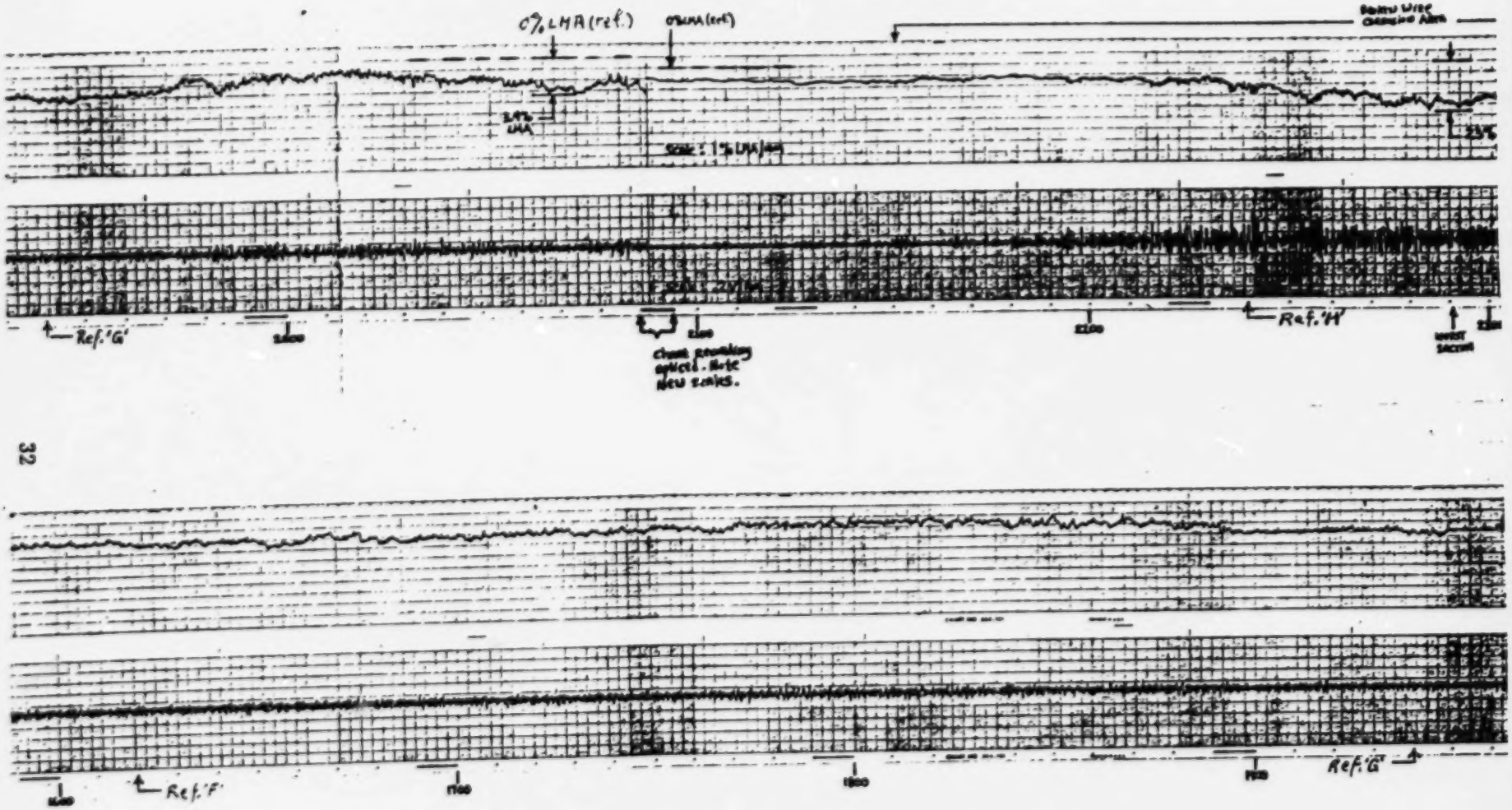


Fig. 4 (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope

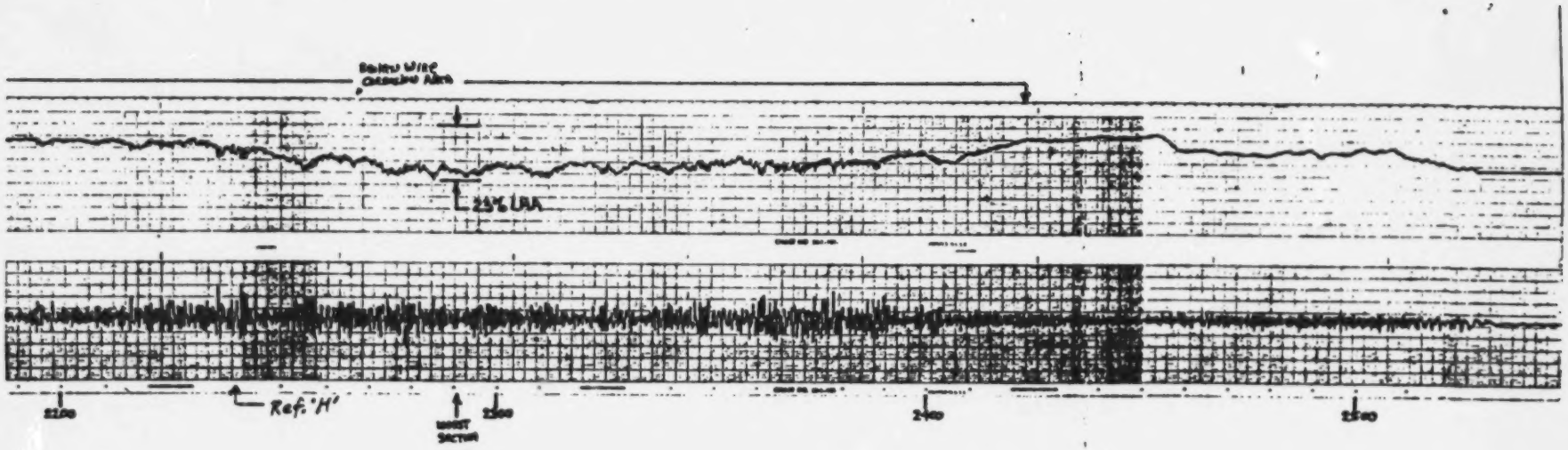


Fig. 4 (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope

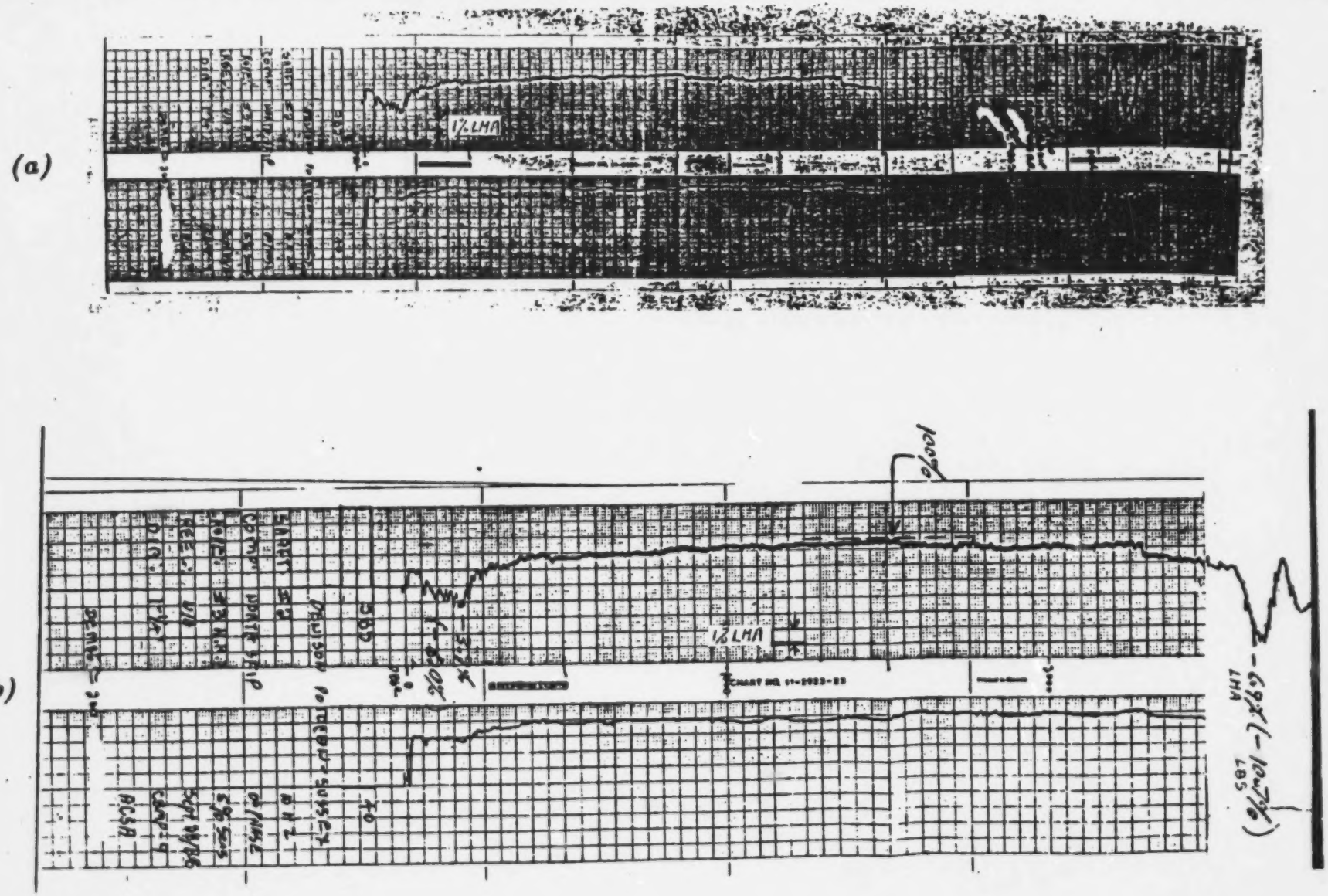
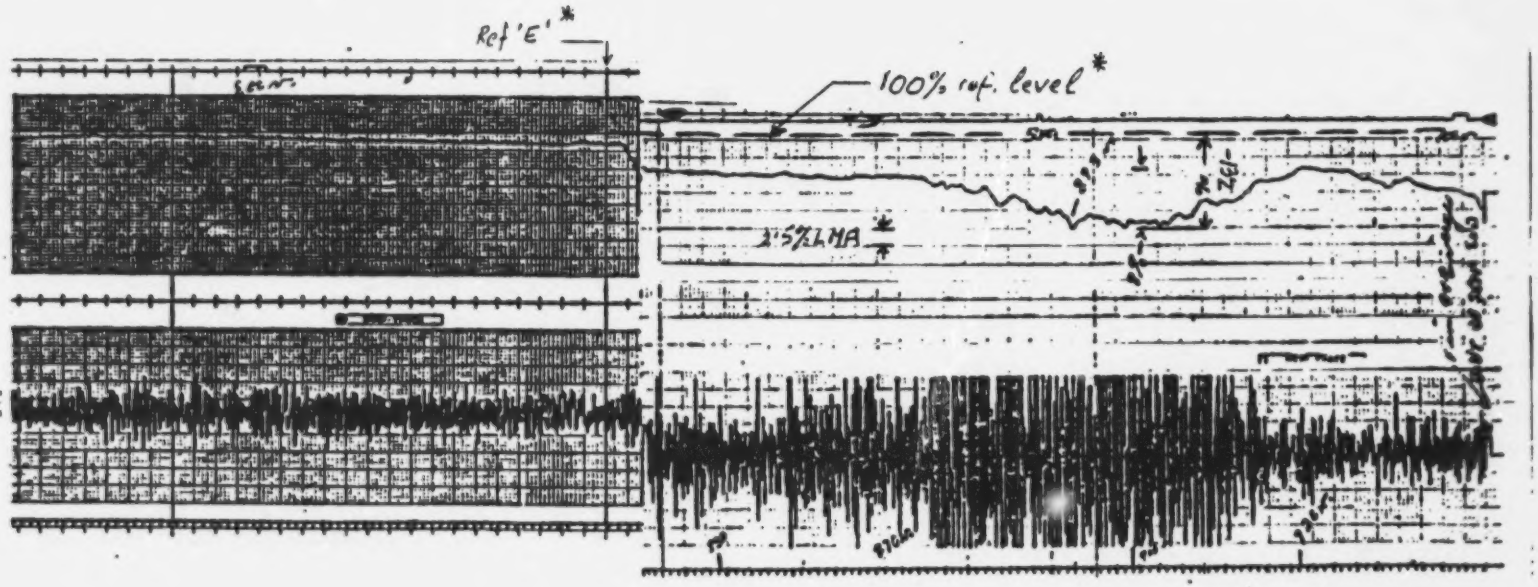


Fig. 5 — 29.9.88, Rotesco AC in situ test #CBMP-9 of 1987-1988 rope; (a) original Rotesco chart (Fig. 2c);

(b) as (a), but reviewed and respliced by authors (LBS data in brackets)



*: as in Fig. 3a

Fig. 6 — Magnograph in situ test of 1987-1988 rope; as Fig. 3b, but reviewed and respliced by authors

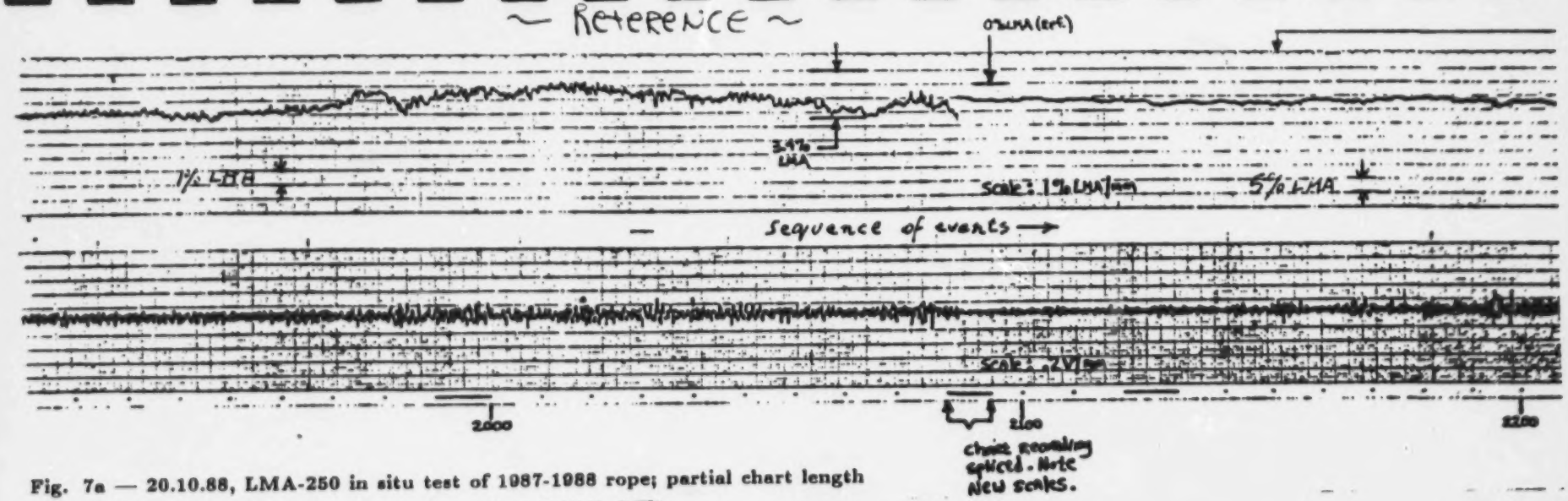


Fig. 7a — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (1,020- 2,210 ft) of Fig. 4

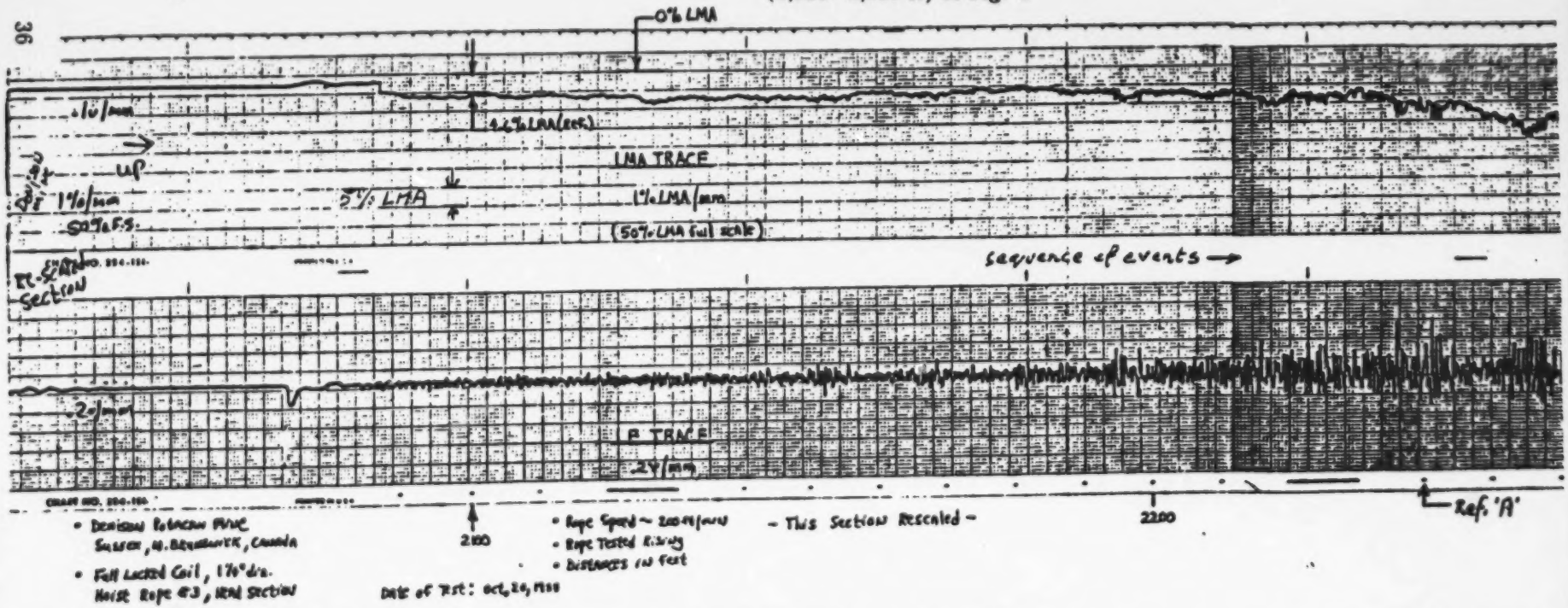


Fig. 7b — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (2,090- 2,540 ft) of Fig. 4, i.e., with LMA-gain resetting at 2,090 ft

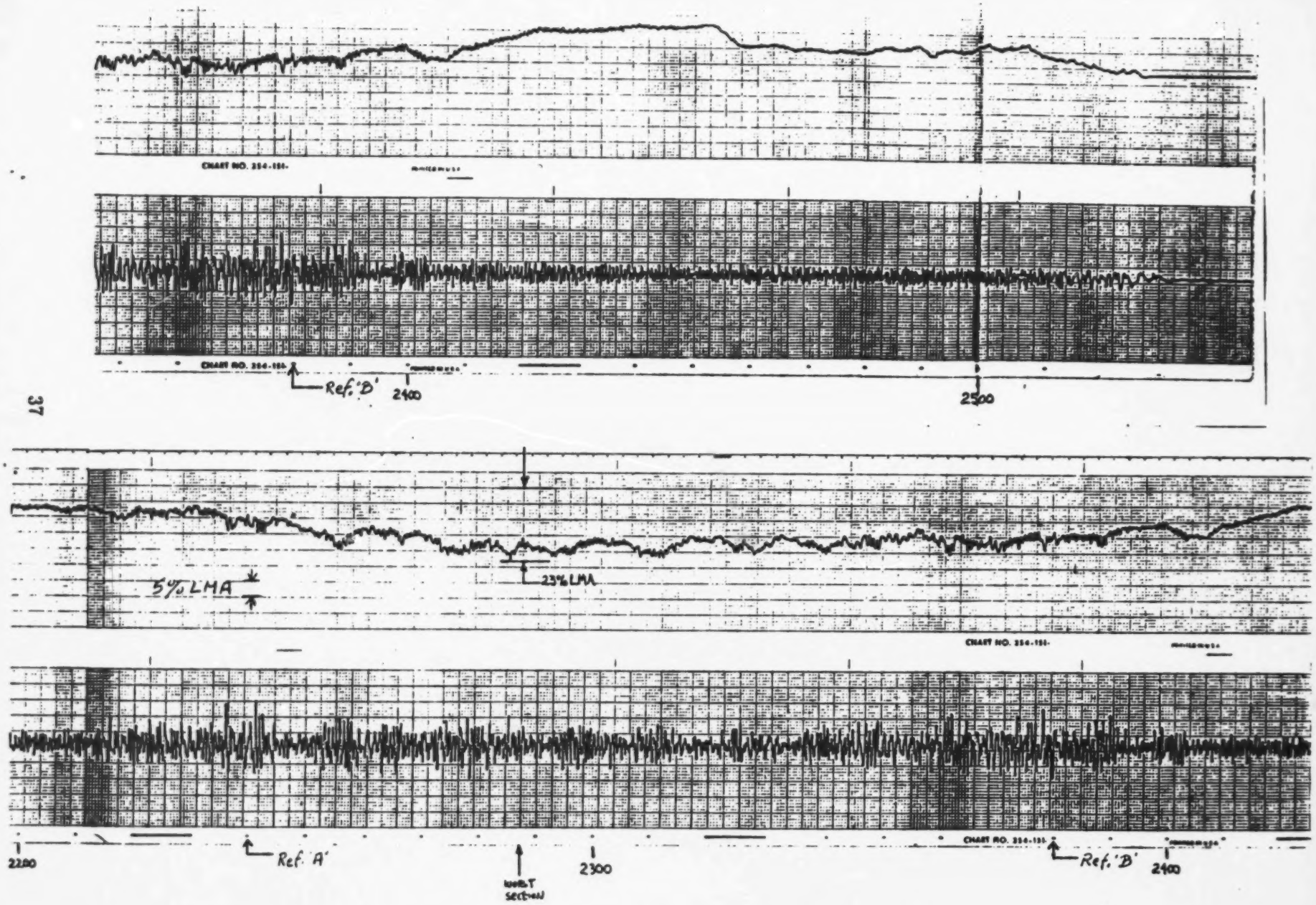


Fig. 7b (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (2,090-2,540 ft) of Fig. 4. i.e., with LMA-gain resetting at 2,000 ft

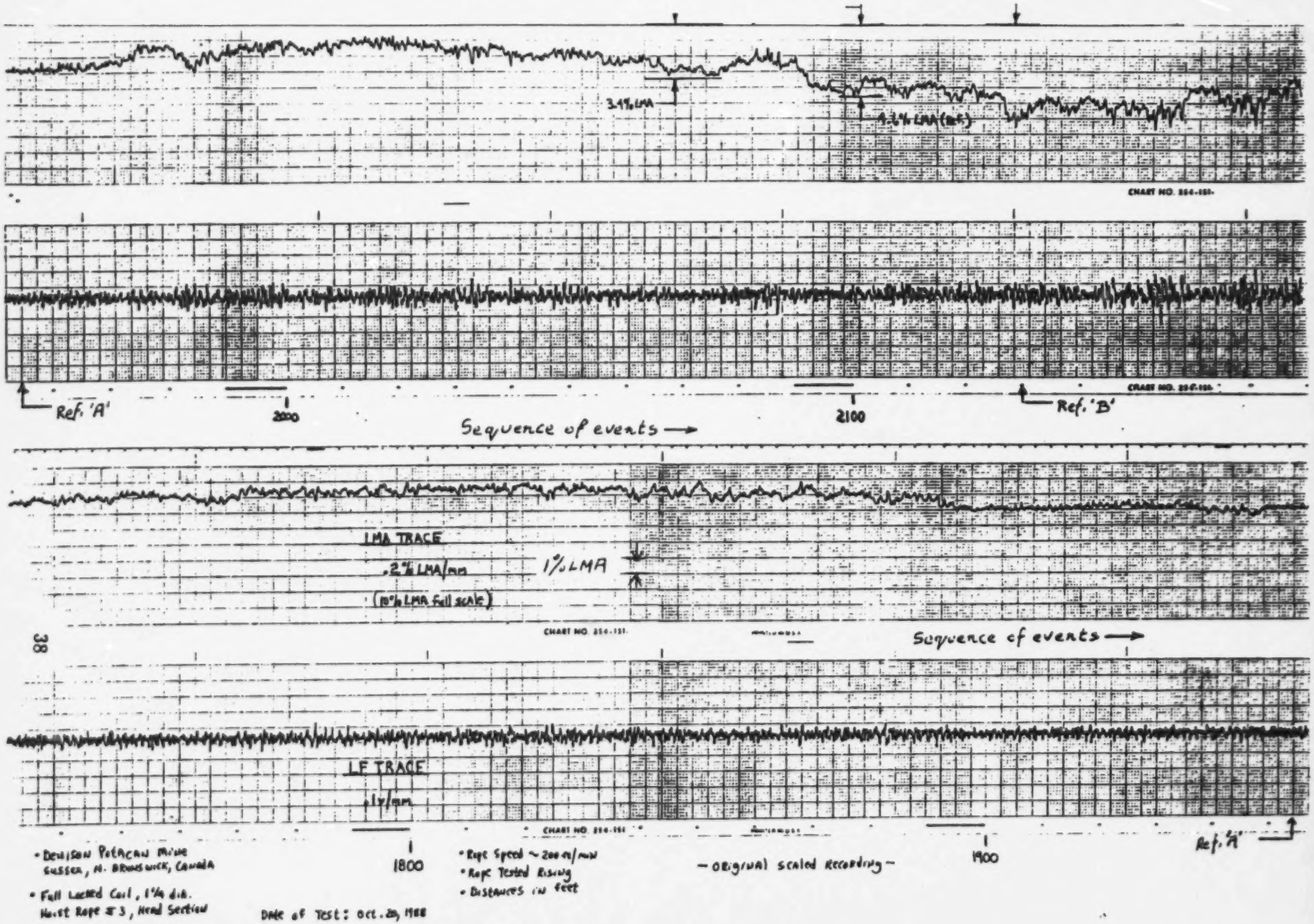


Fig. 7c — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (2,090- 2,540 ft) of Fig. 4,

but with no LMA gain resetting at 2,000 ft

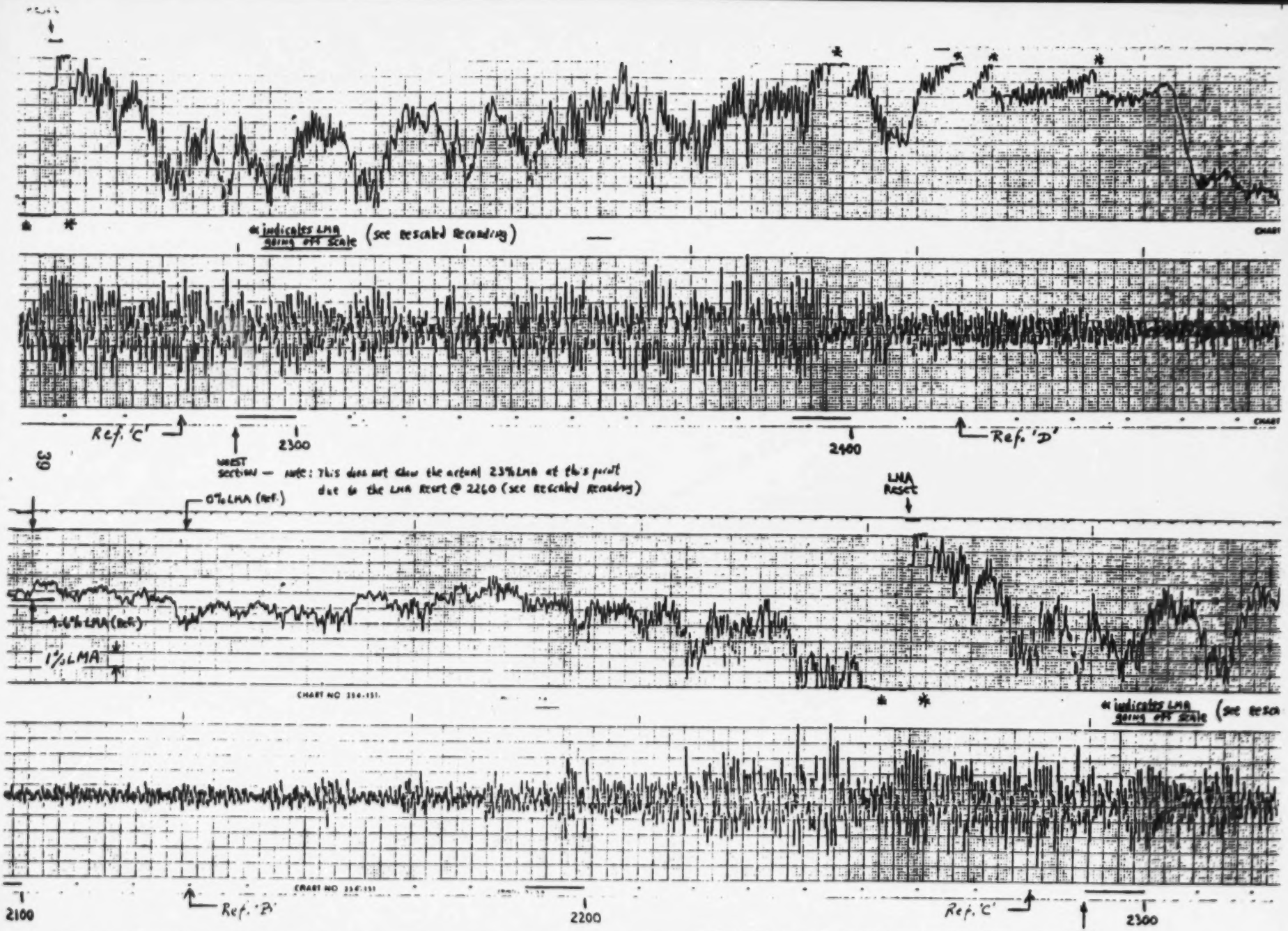


Fig. 7c (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (2,090-2,540 ft) of Fig. 4, but with no LMA-gain resetting at 2,090 ft

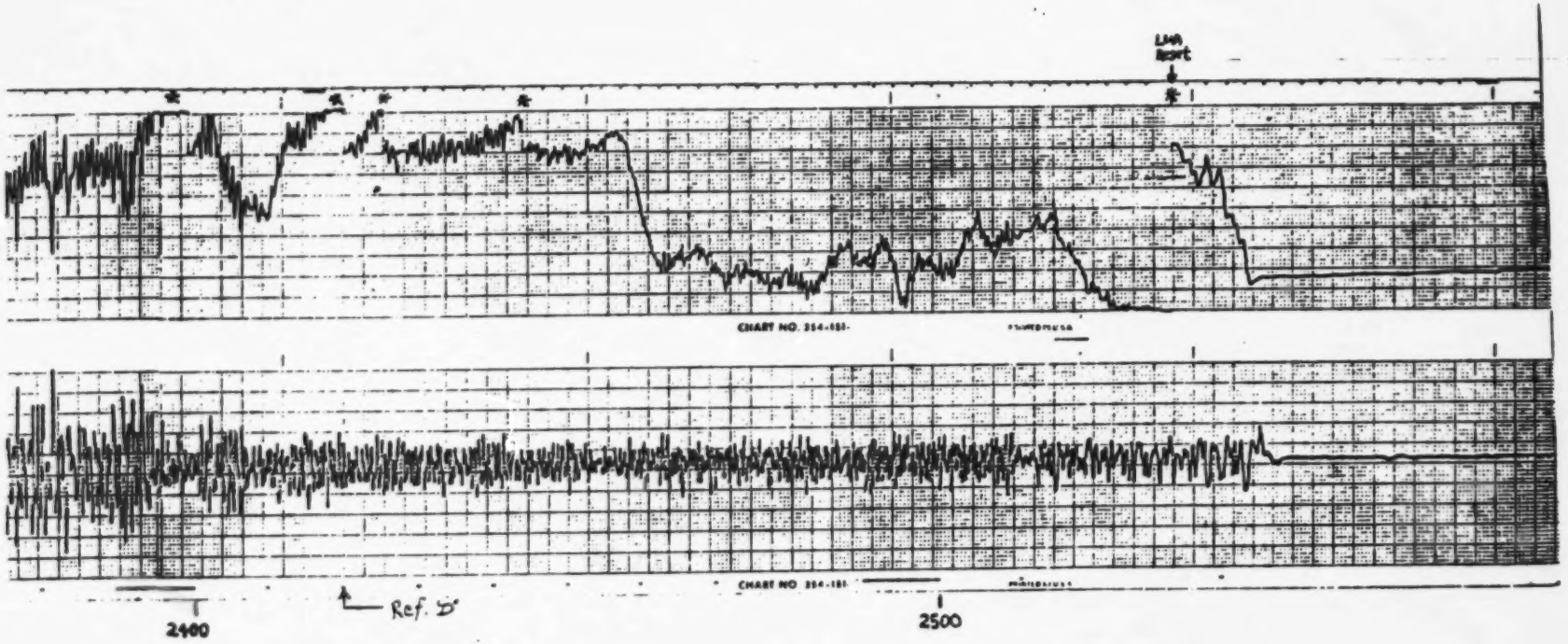


Fig. 7c (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (2,090-2,540 ft) of Fig. 4, but with no LMA-gain resetting at 2,090 ft

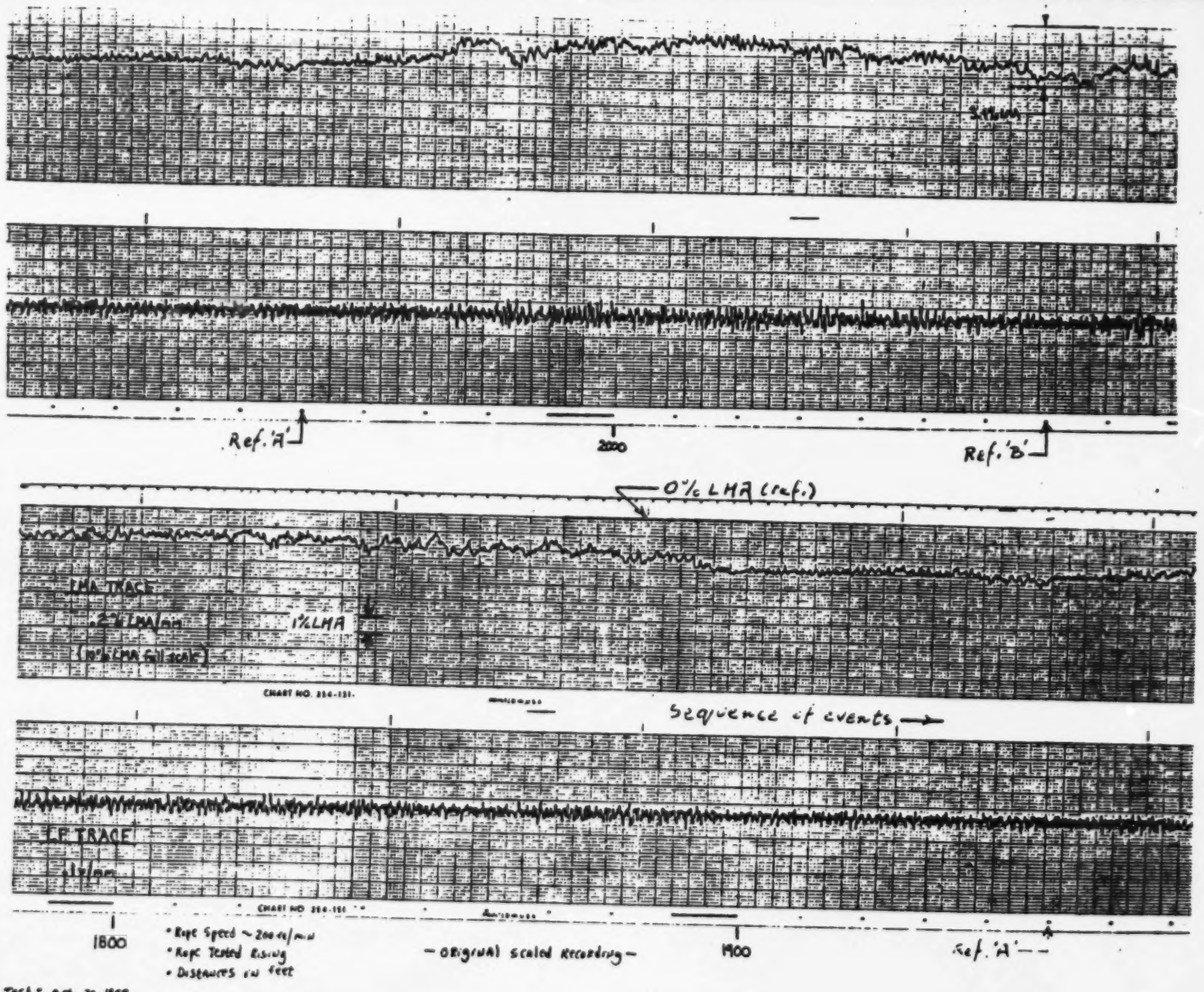


Fig. 7d — 20.10.88, LMA-250 in situ test of 1987-1988 rope; as Fig. 7c, but realigned and respliced by authors

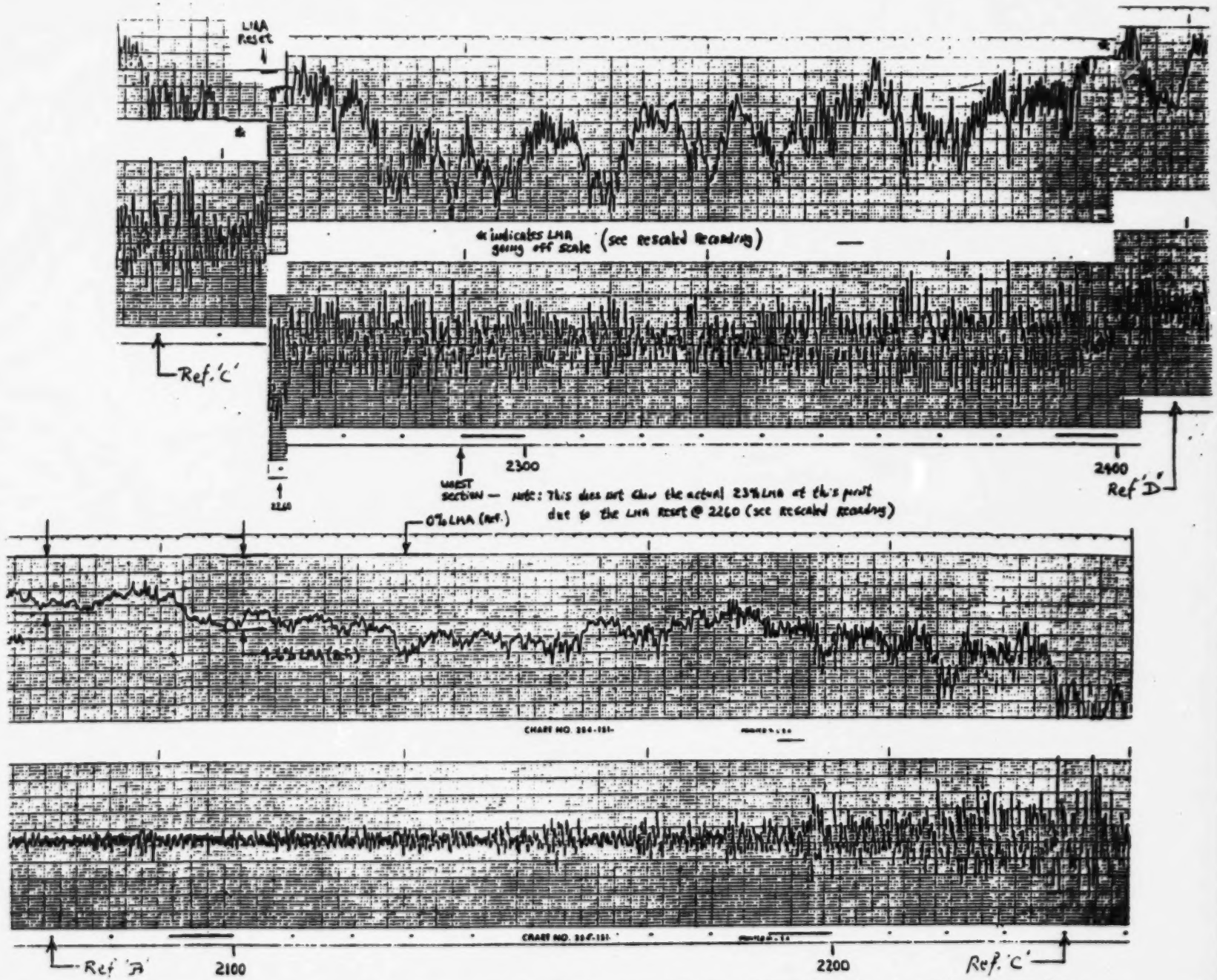


Fig. 7d (continued) — 20.10.88 LMA-250 in situ test of 1987-1988 range as Fig. 7c, but realigned and reoriented by authors

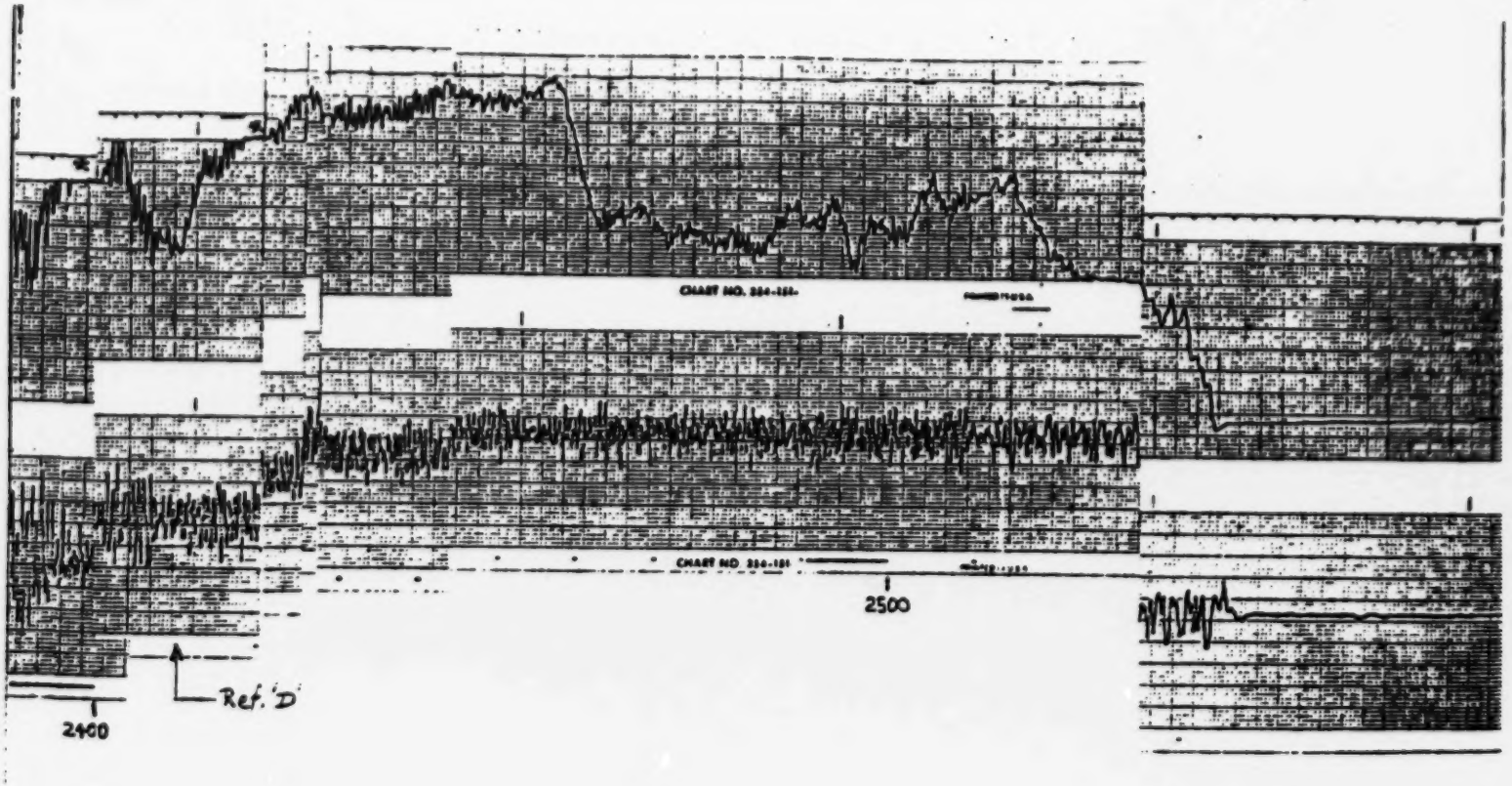


Fig. 7d (continued) — 20.10.88, LMA-250 in situ test of 1987-1988 rope; as Fig. 7c, but realigned and respliced by authors

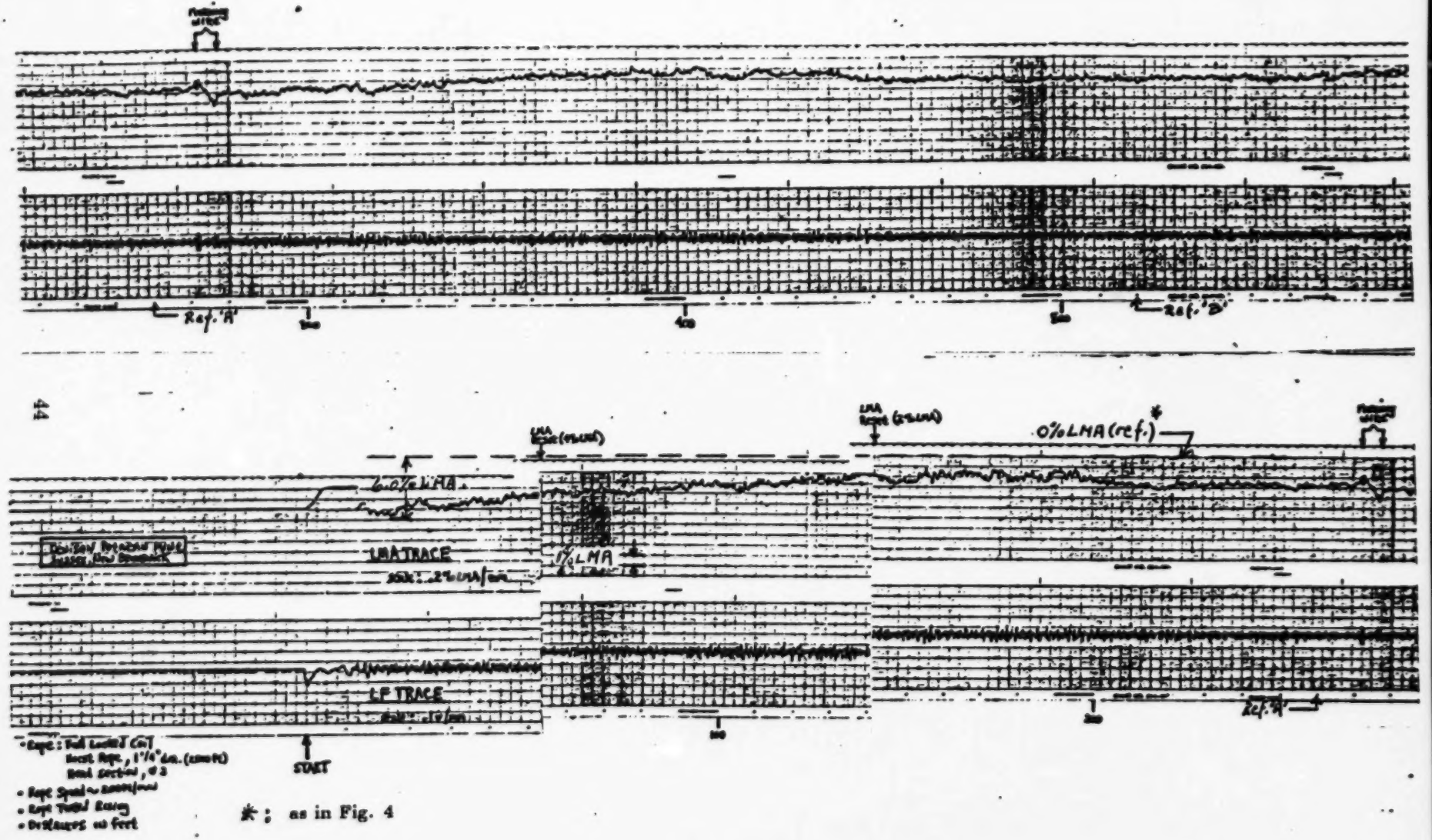
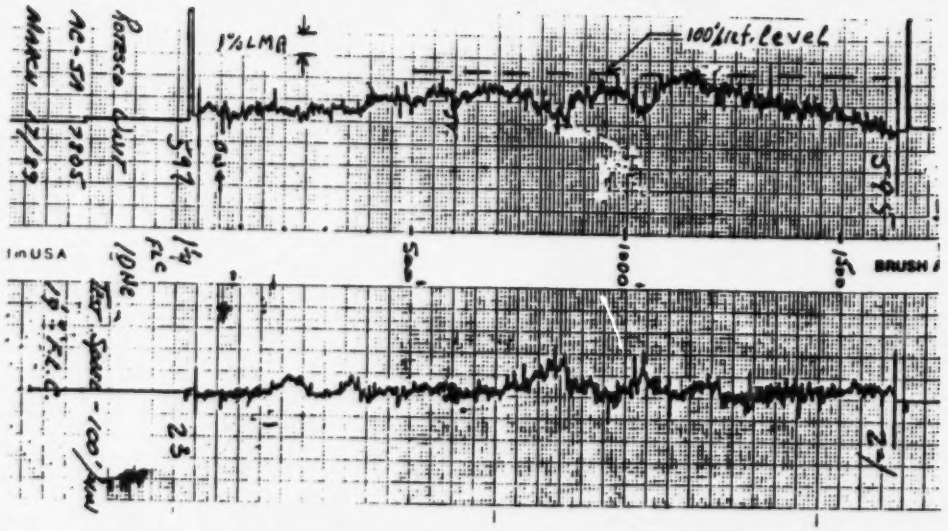


Fig. 7e — 20.10.88, LMA-250 in situ test of 1987-1988 rope; partial chart length (0-550 ft)

of Fig. 4, as reviewed and respliced by authors

Fig. 8a —

17.3.89, Rotesco AC shop-floor test of part of 1987-1988 rope (only 1,600 ft tested)



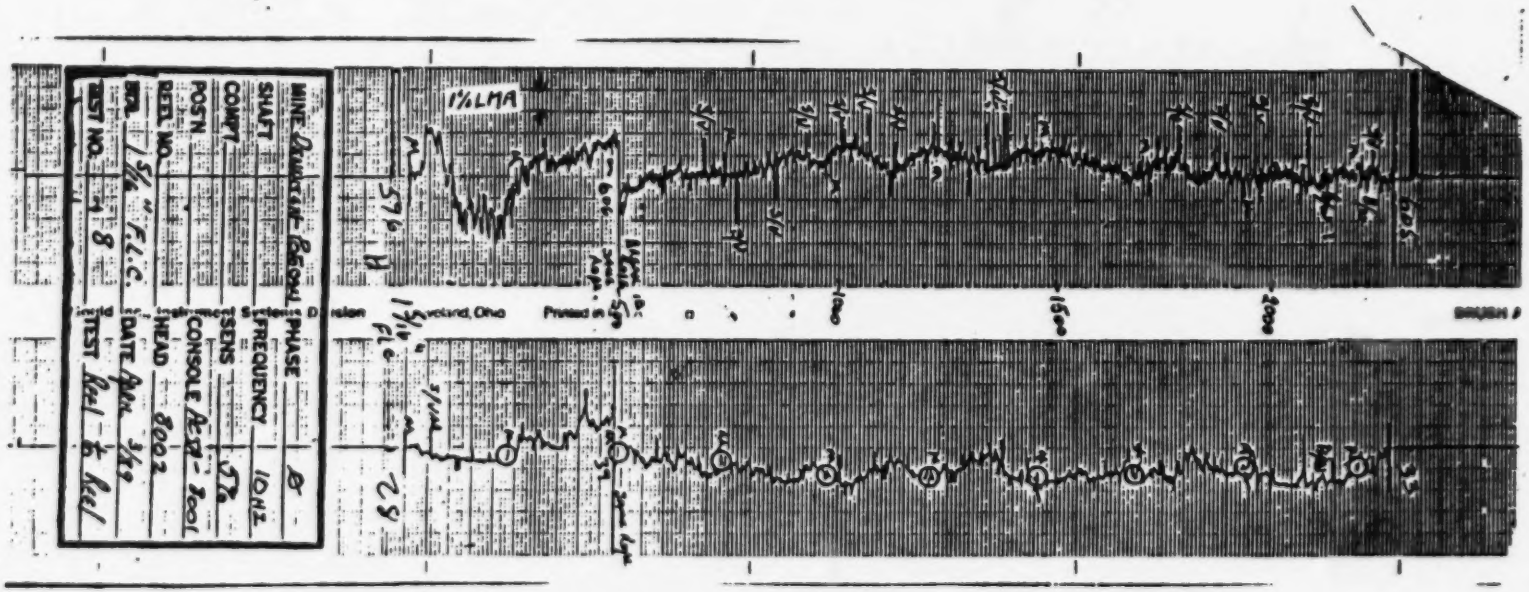


Fig. 8b — 3.4.89, Rotesco AC shop-floor test of 1987-1988 rope (2,700 ft tested)

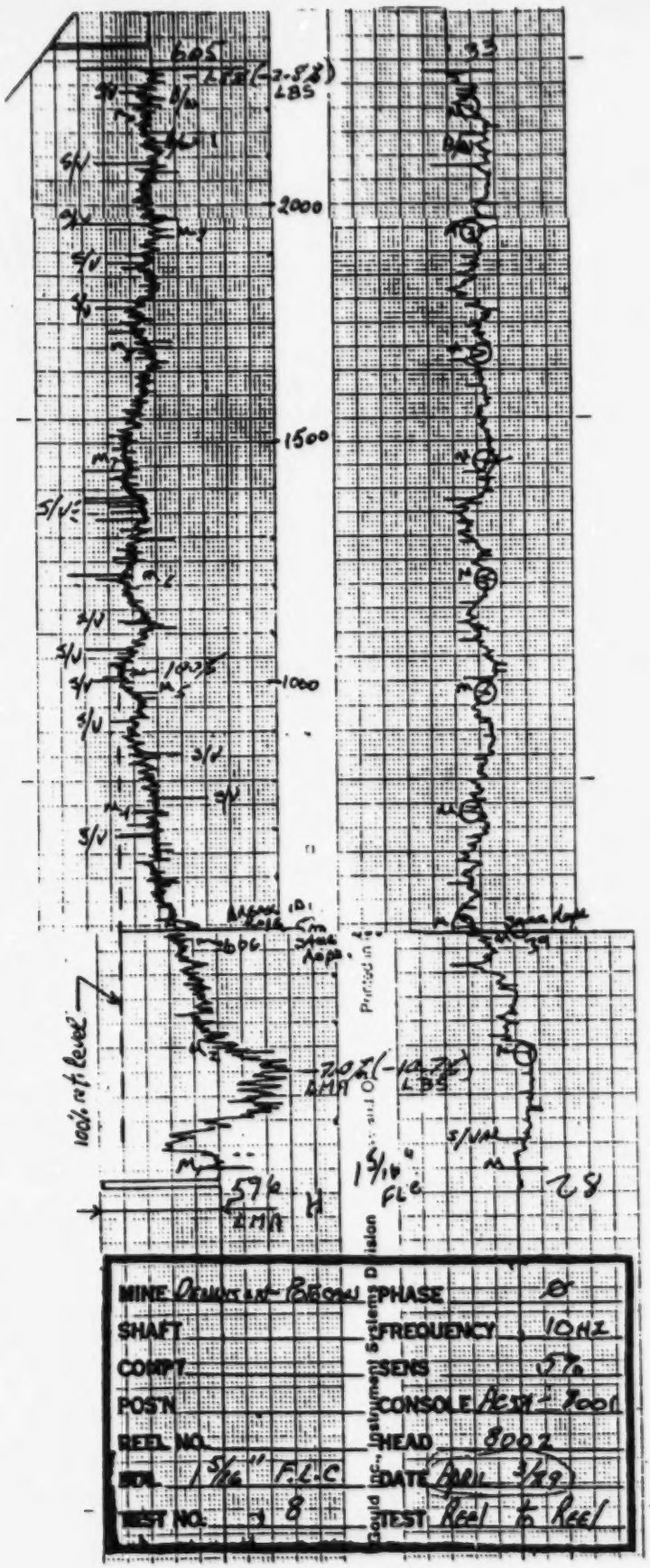


Fig. 8c — 3.4.89, Rotesco AC shop-floor test of 1987-1988 rope; authors' analysis of Fig. 8b, with realignment and resplicing

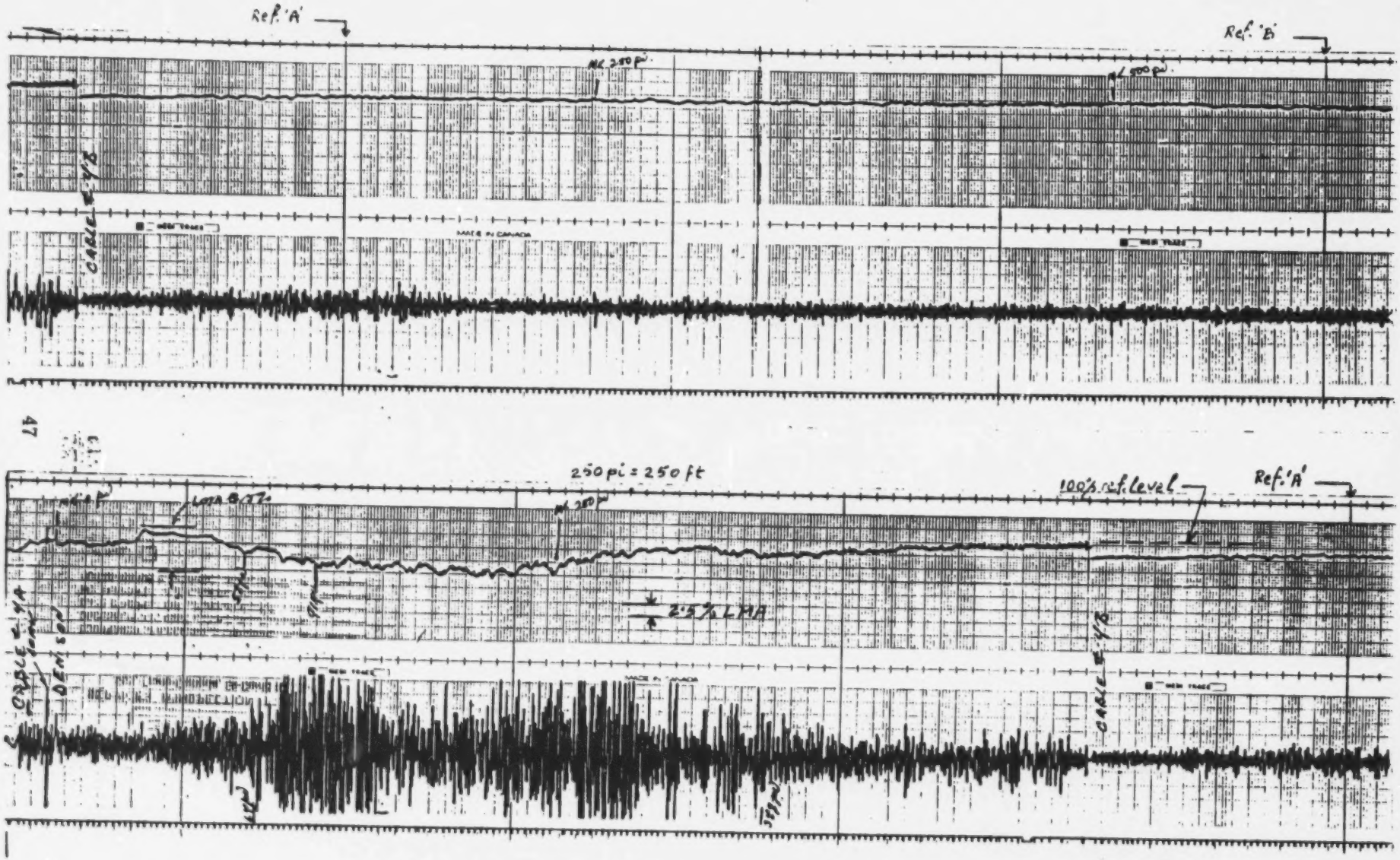


Fig. 9a — 4.4.89, Magnograph shop-floor test of 1987-1988 rope (2,350 ft tested)

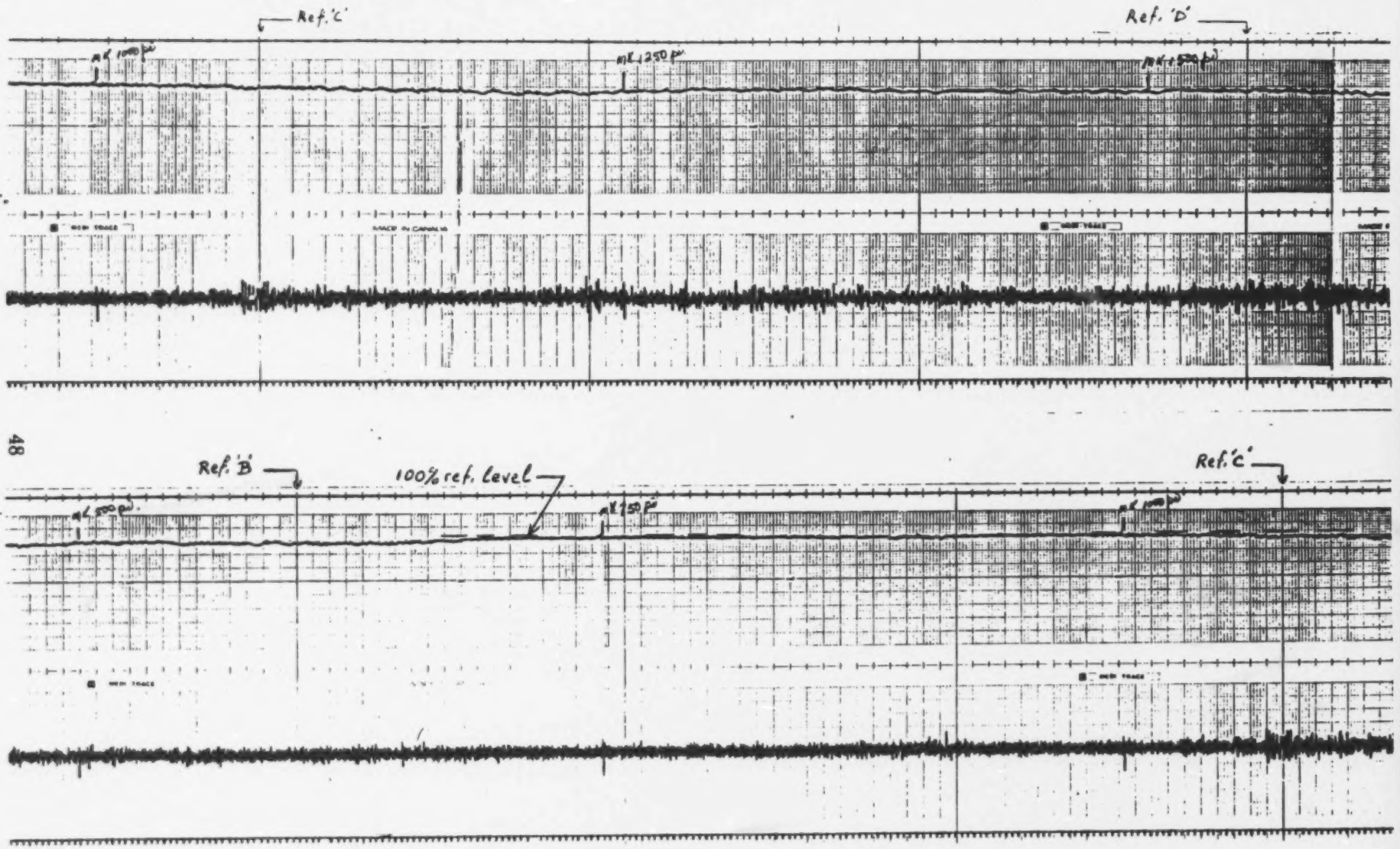


Fig. 9a (continued) — 4.4.89, Magnograph shop-floor test of 1987-1988 rope (2,350 ft tested)

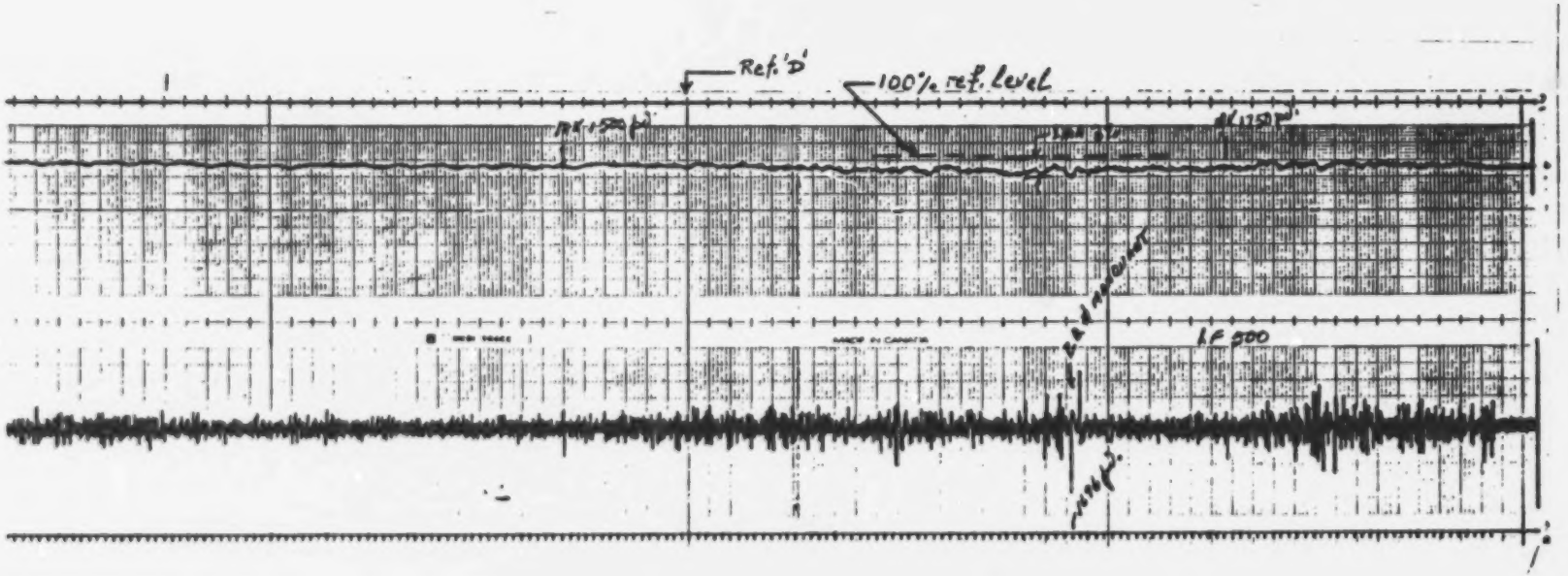
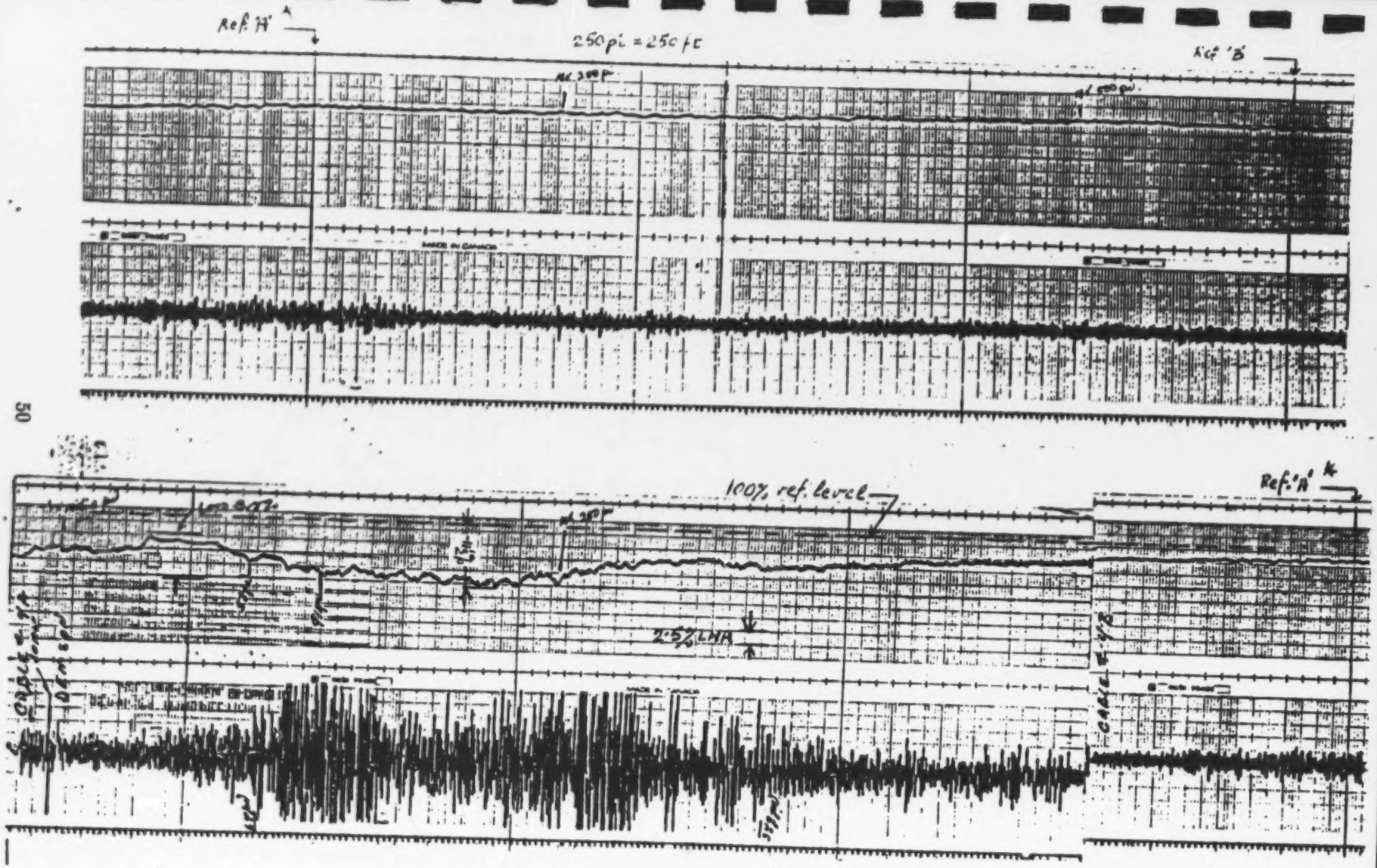


Fig. 9a (continued) — 4.4.80, Magnograph shop-floor test of 1987-1988 rope (2,350 ft tested)



*: as in Fig. 9a

Fig. 9b — 4.4.80, Magnograph shop-floor test of 1987-1988 rope; authors' analysis of Fig. 9a, with realignment and reaplicing

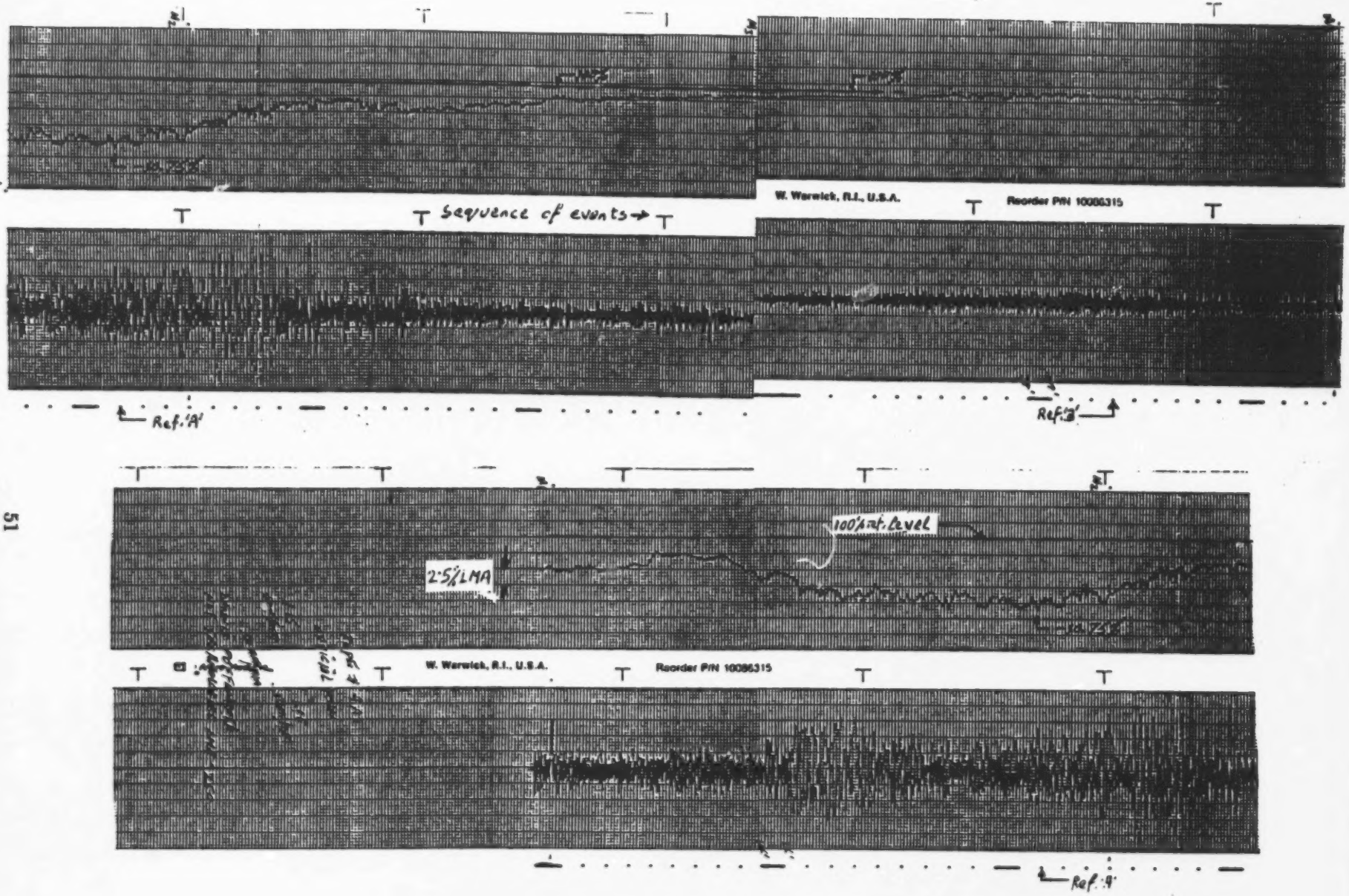


Fig. 10 — 4.4.80, LMA-250 shop-floor test of 1987-1988 rope (2,300 ft tested)

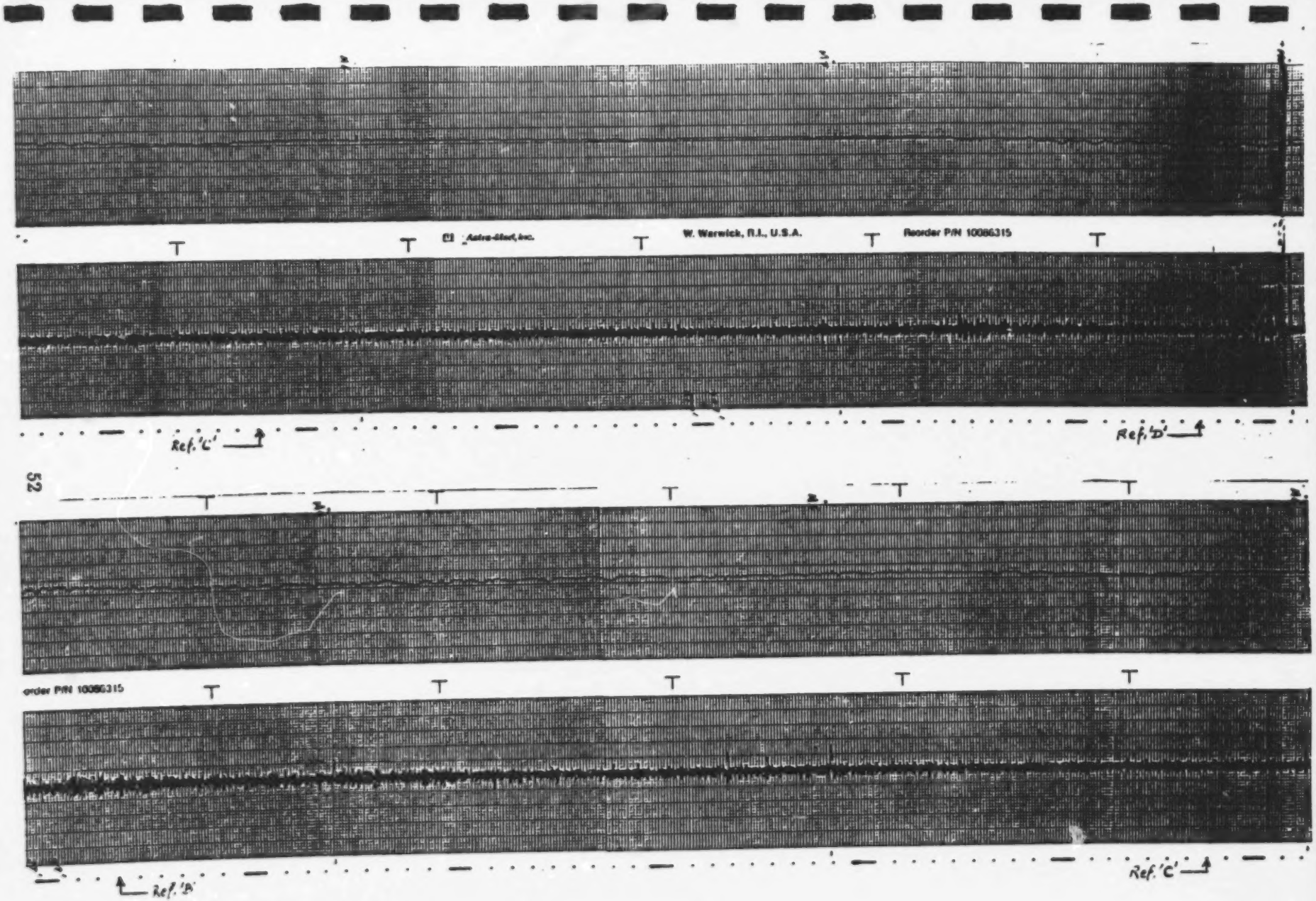


Fig. 10 (continued) — 4.4.89, LMA-250 shop-floor test of 1987-1988 rope (2,300 ft tested)

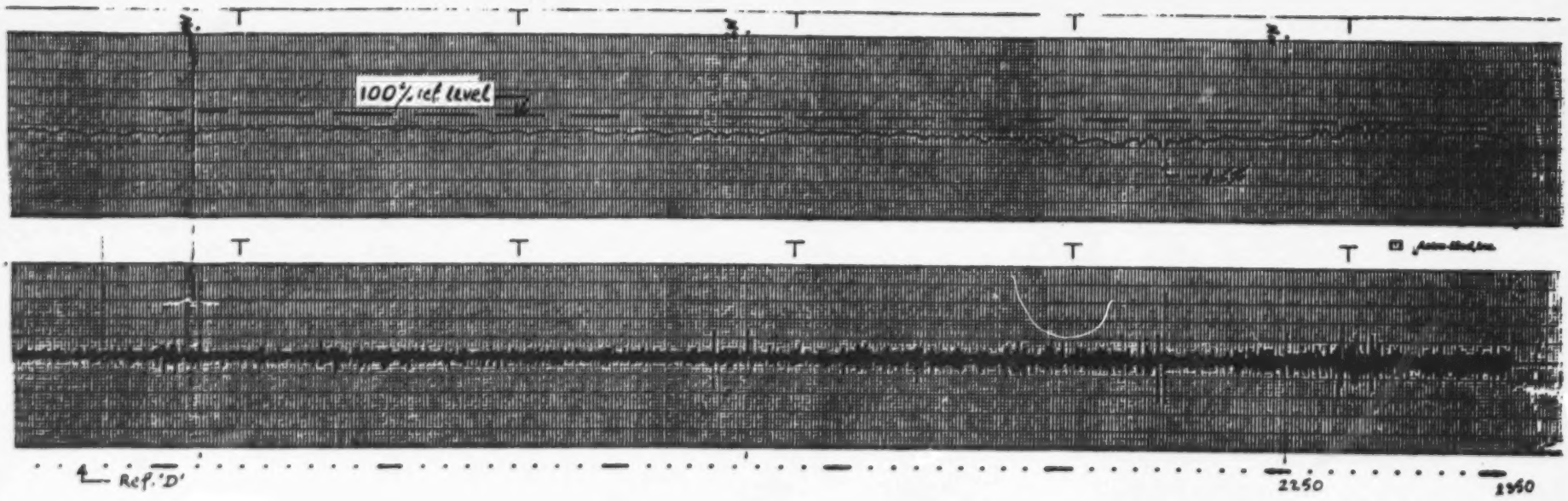


Fig. 10 (continued) — 4.4.89, LMA-250 shop-floor test of 1987-1988 rope (2,300 ft tested)

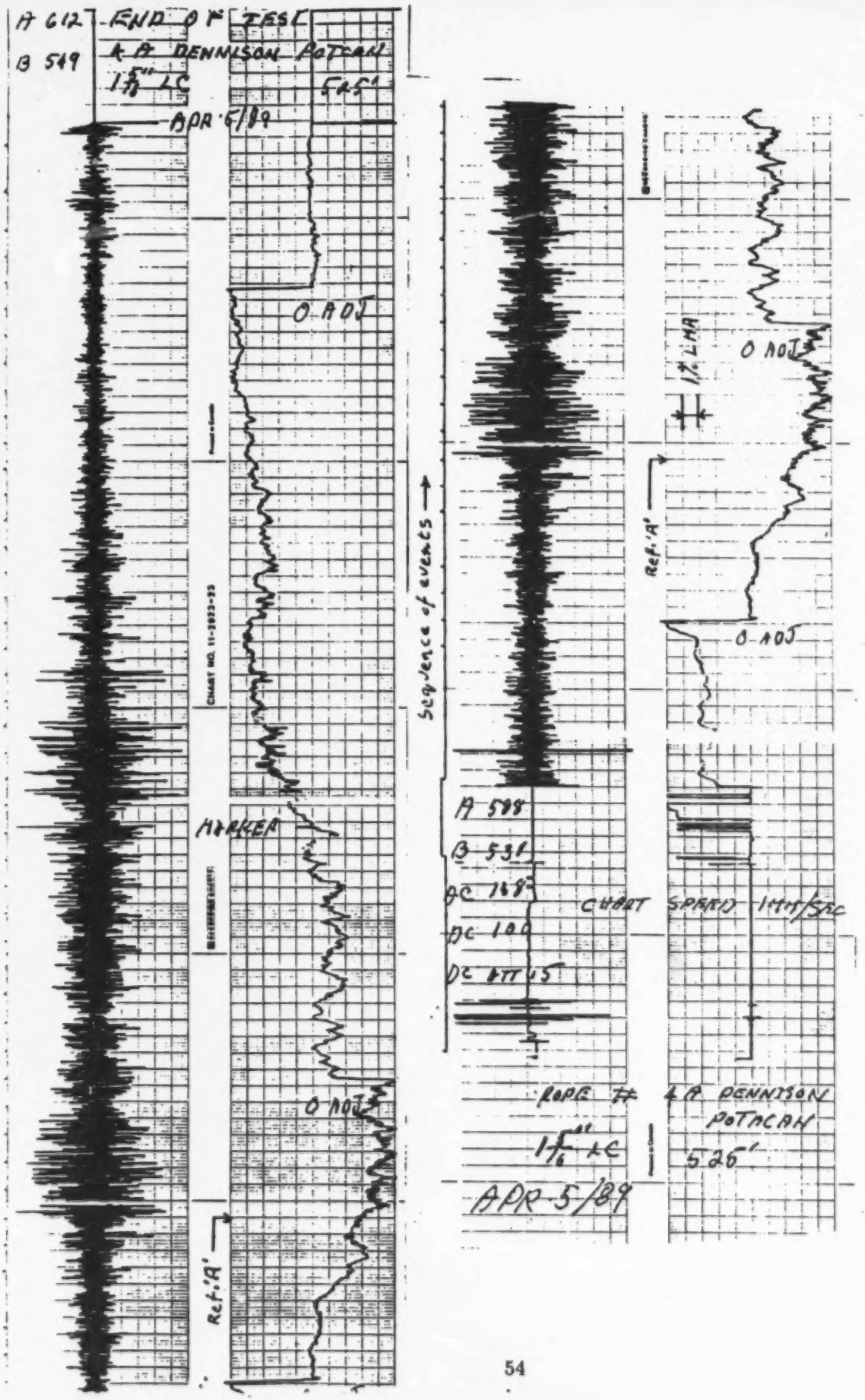


Fig. 11a — Rotencograph shop-floor test of 1987-1988 rope; 6.4.89 test of 500 ft rope section (rope #4A).

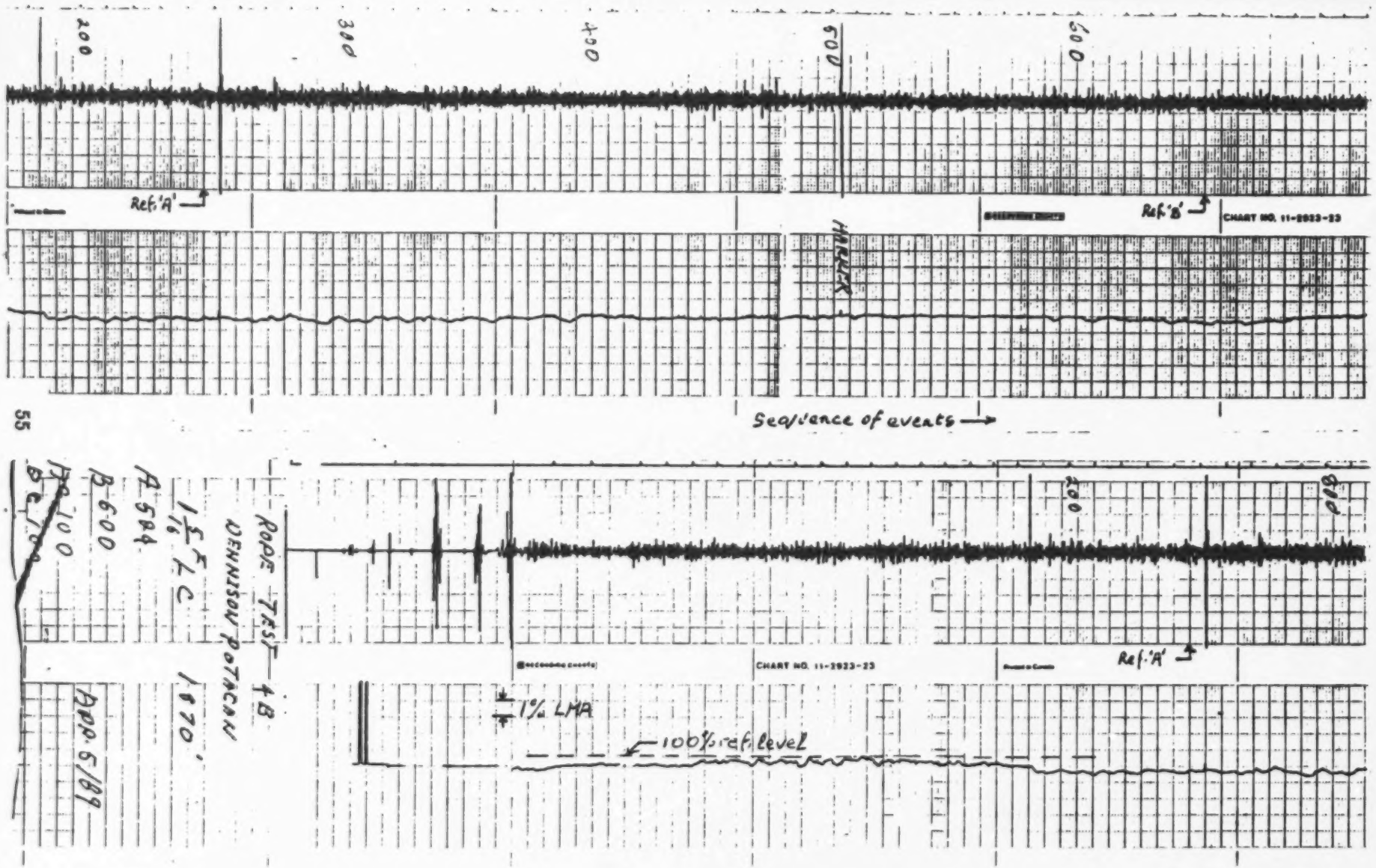


Fig. 11b — Rotescograph shop-floor test of 1987-1988 rope; 5.4.89 test of 1,850 ft rope section (rope #4B)

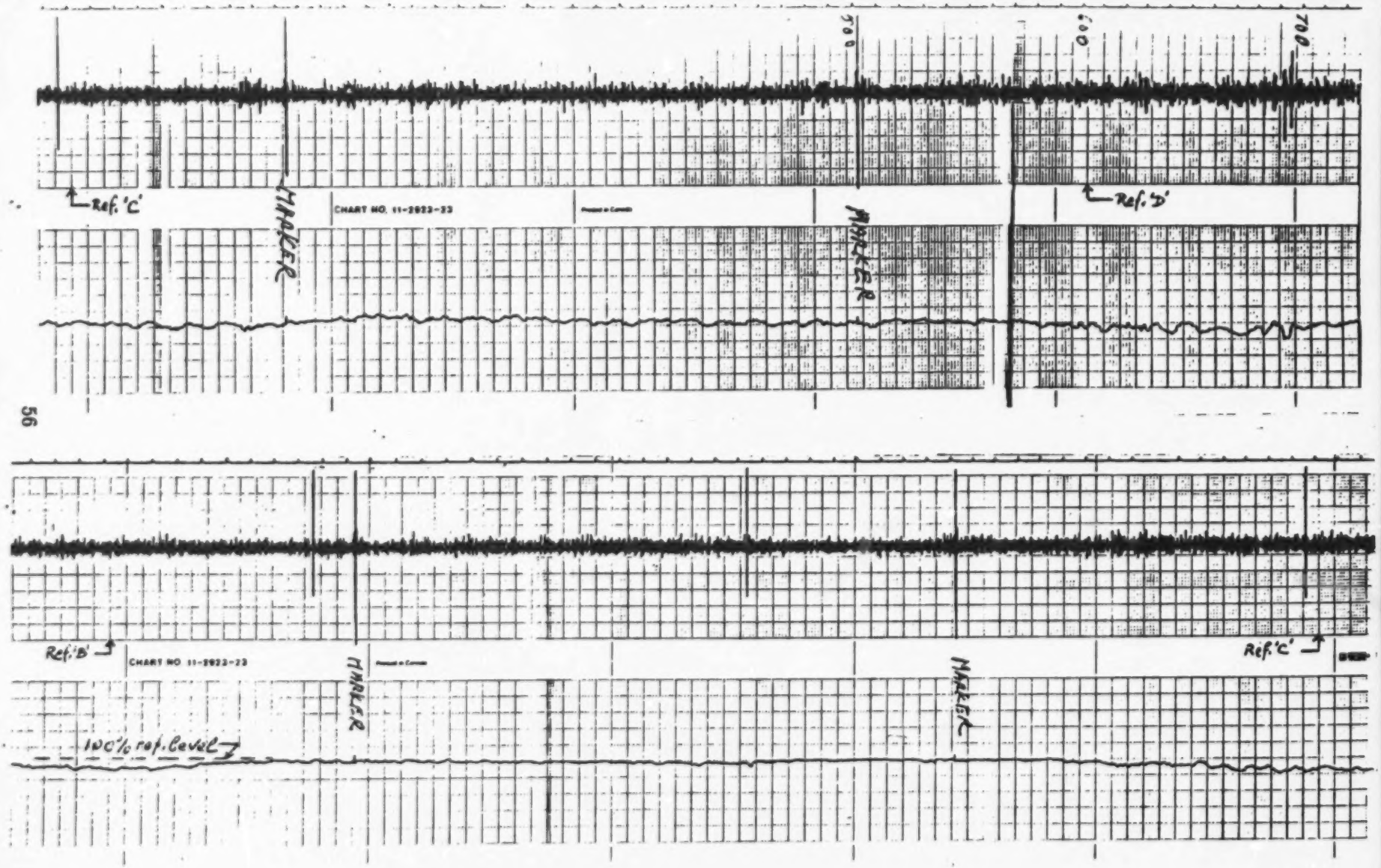


Fig. 11b (continued) — Rotescograph shop-floor test of 1987-1988 rope; 5.4.89 test of 1,850 ft rope section (rope #4B)

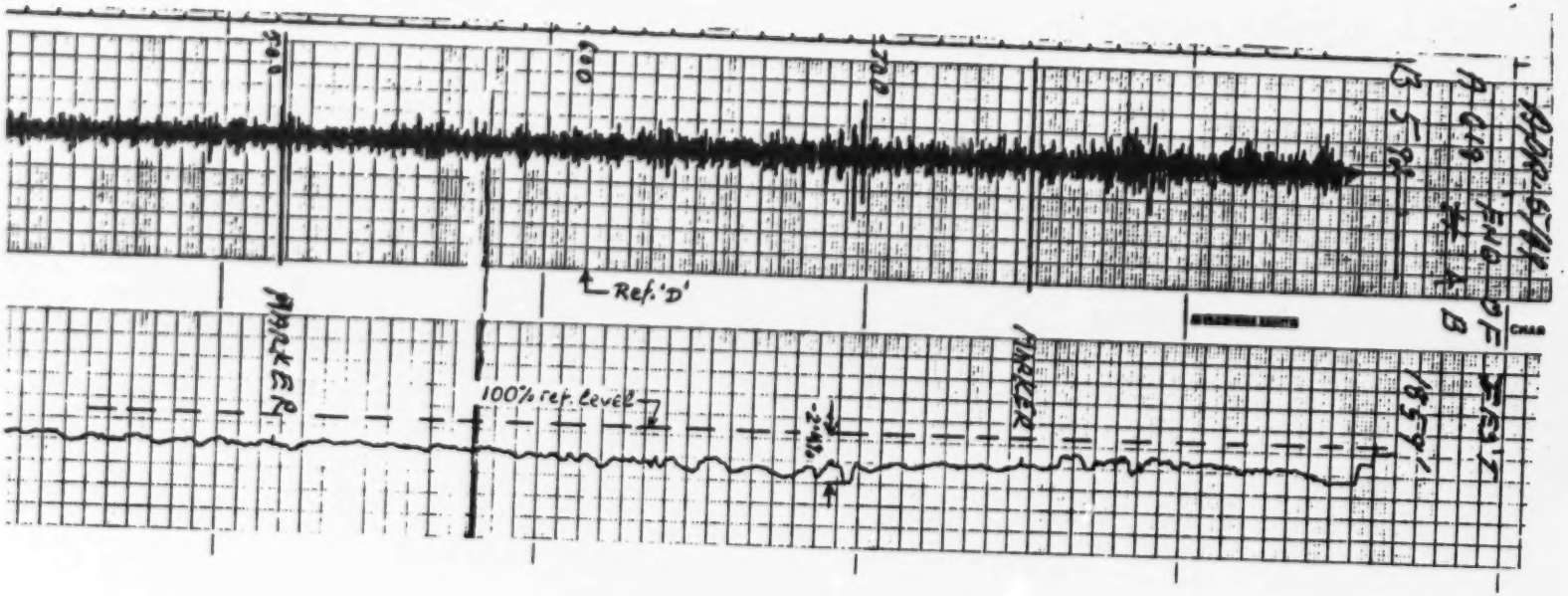


Fig. 11b (continued) — Rotescograph shop-floor test of 1987-1988 rope; 5.4.89 test of 1,850 ft rope section (rope #4B)

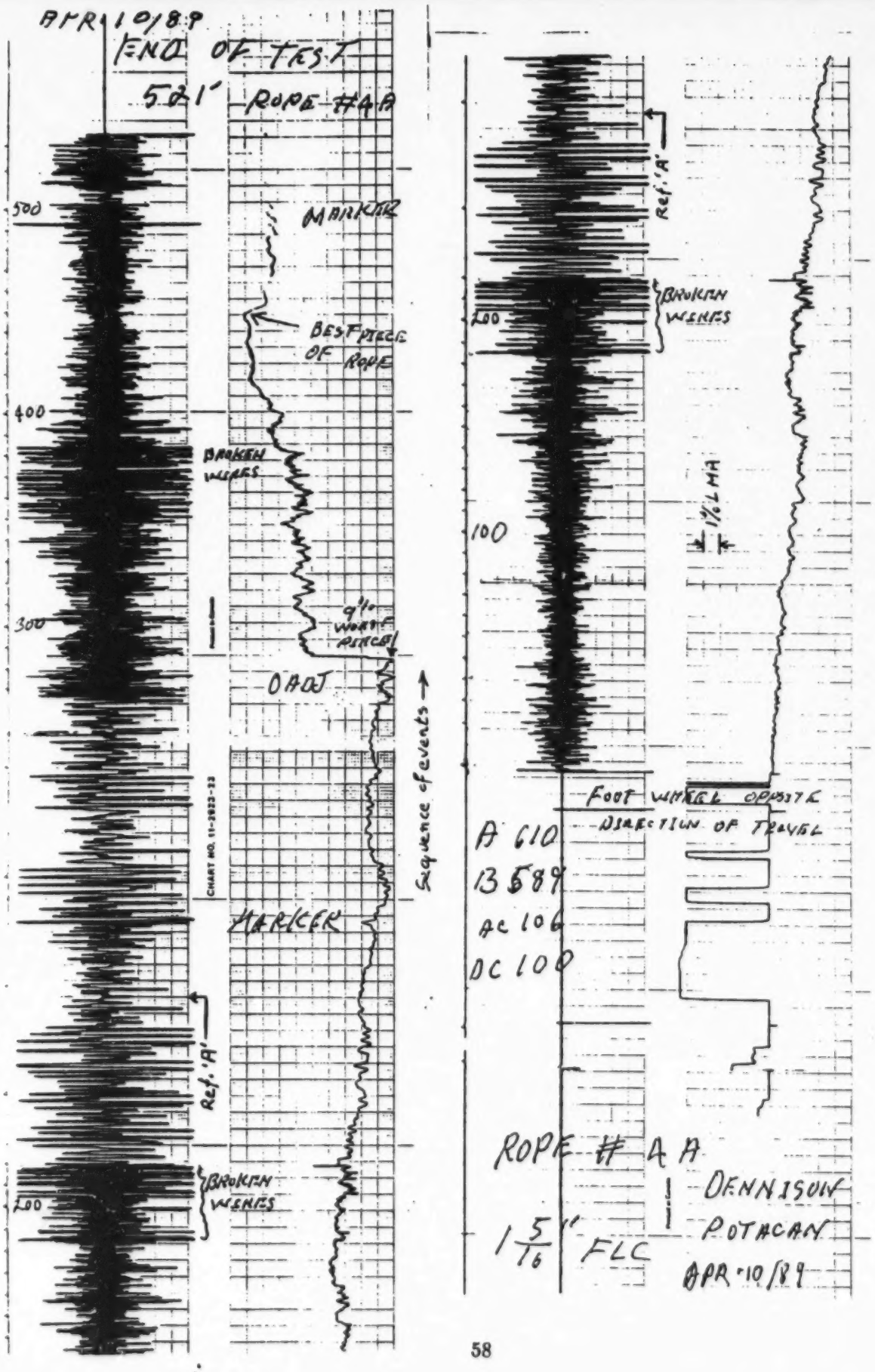


Fig. 11c — Rotescograph shop-floor test of 1987-1988 rope; 10.4.89 test of 500 ft rope section (rope #4A).

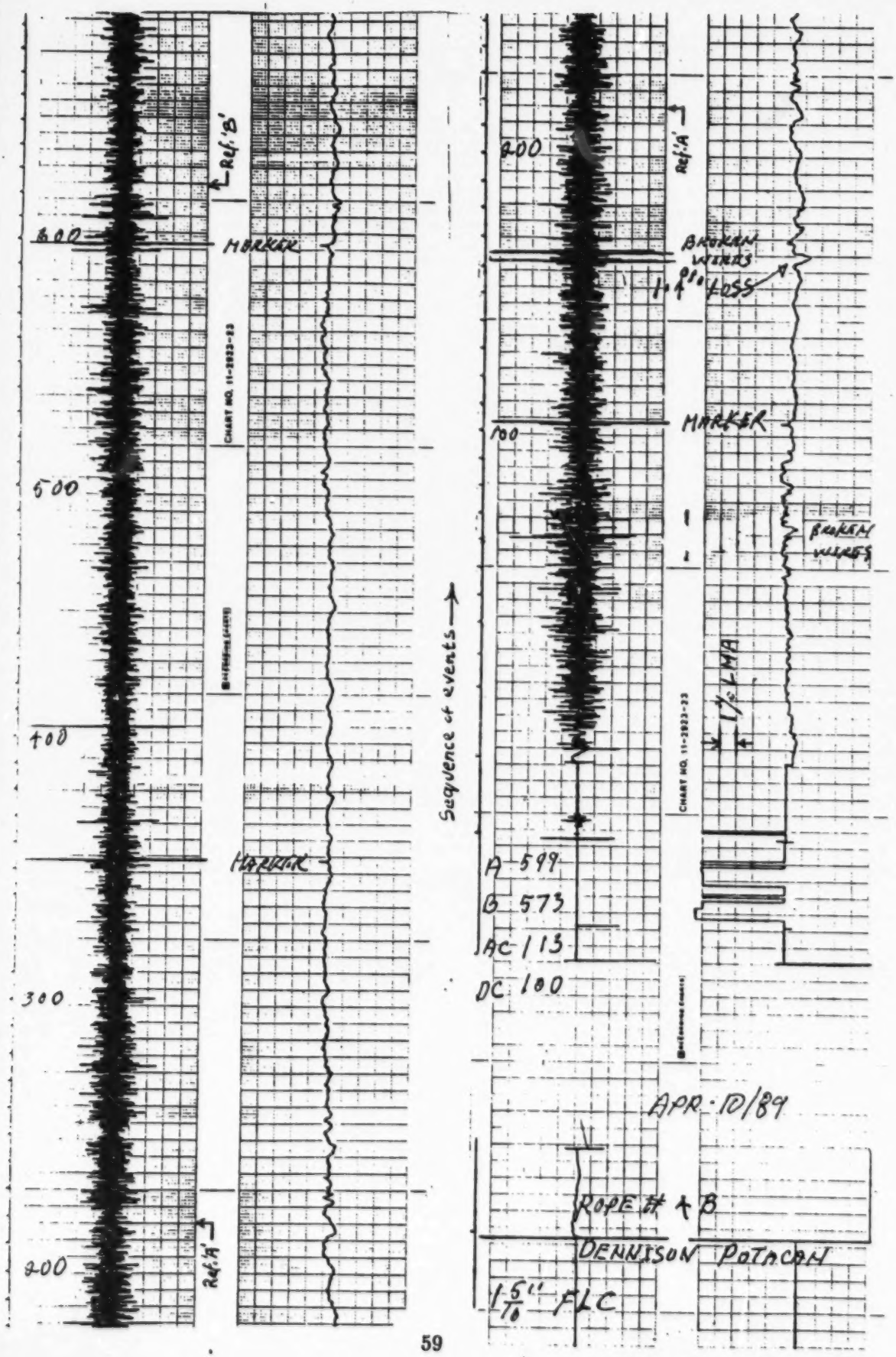


Fig. 11d — Rotescograph shop-floor test of 1987-1988 rope; 10.4.89 test of 1,850 ft rope section (rope #4B)

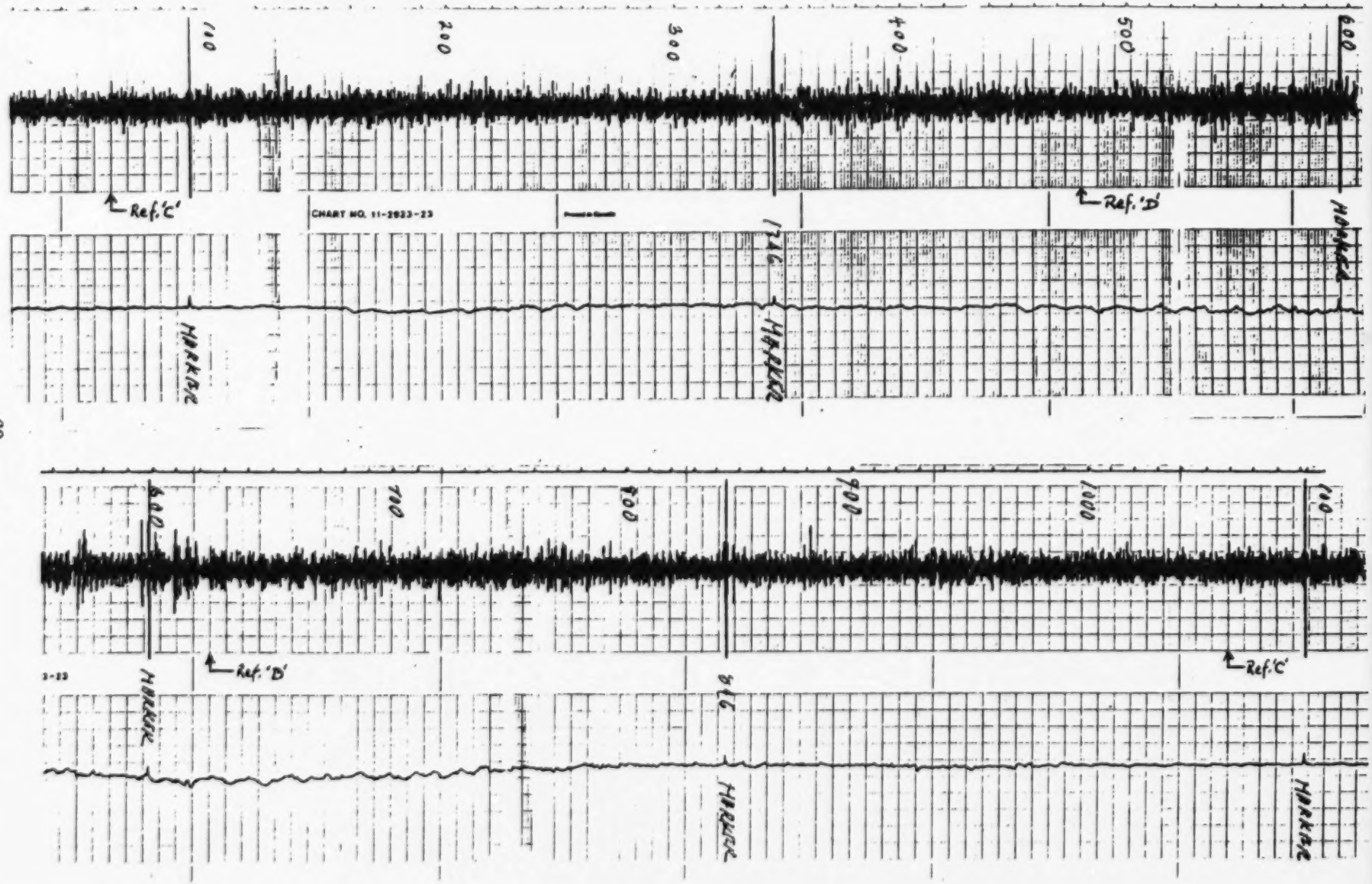


Fig. 11d (continued) — Rotescograph shop-floor test of 1987-1988 rope; 10.4.80 test of 1,850 ft rope section (rope #4B)

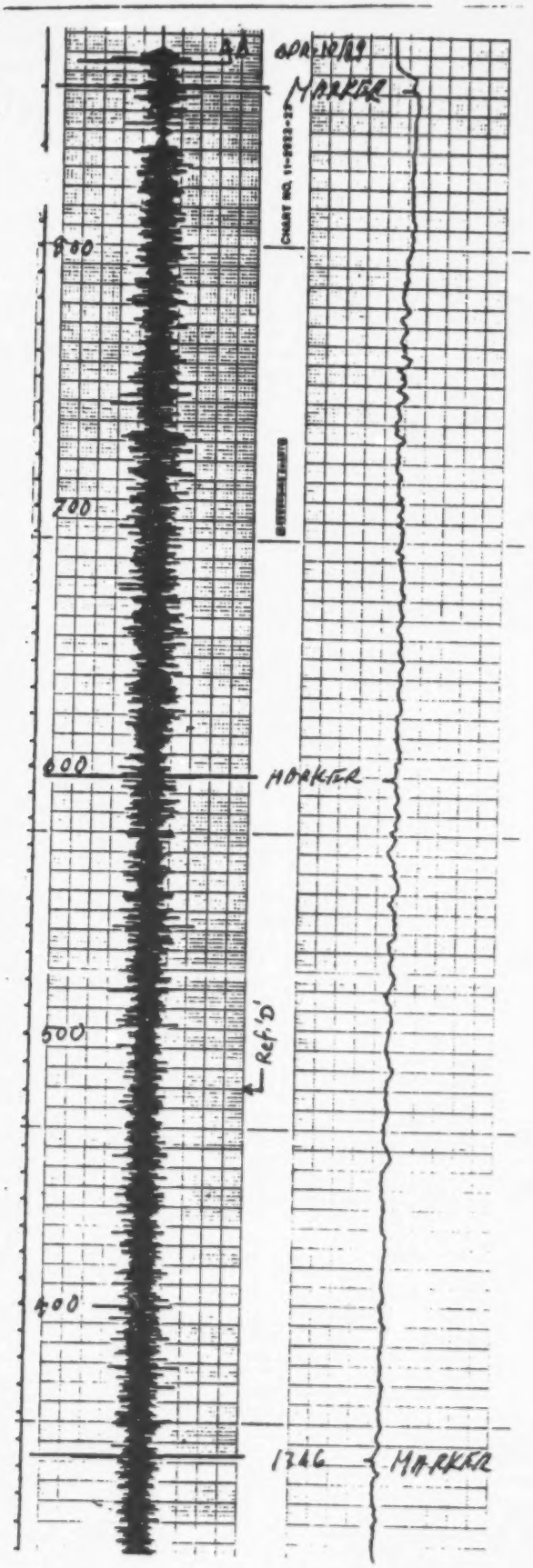


Fig. 11d (continued) — Rotescograph shop-floor test of 1987-1988 rope; 10.4.89 test of 1,850 ft rope section (rope #4B)

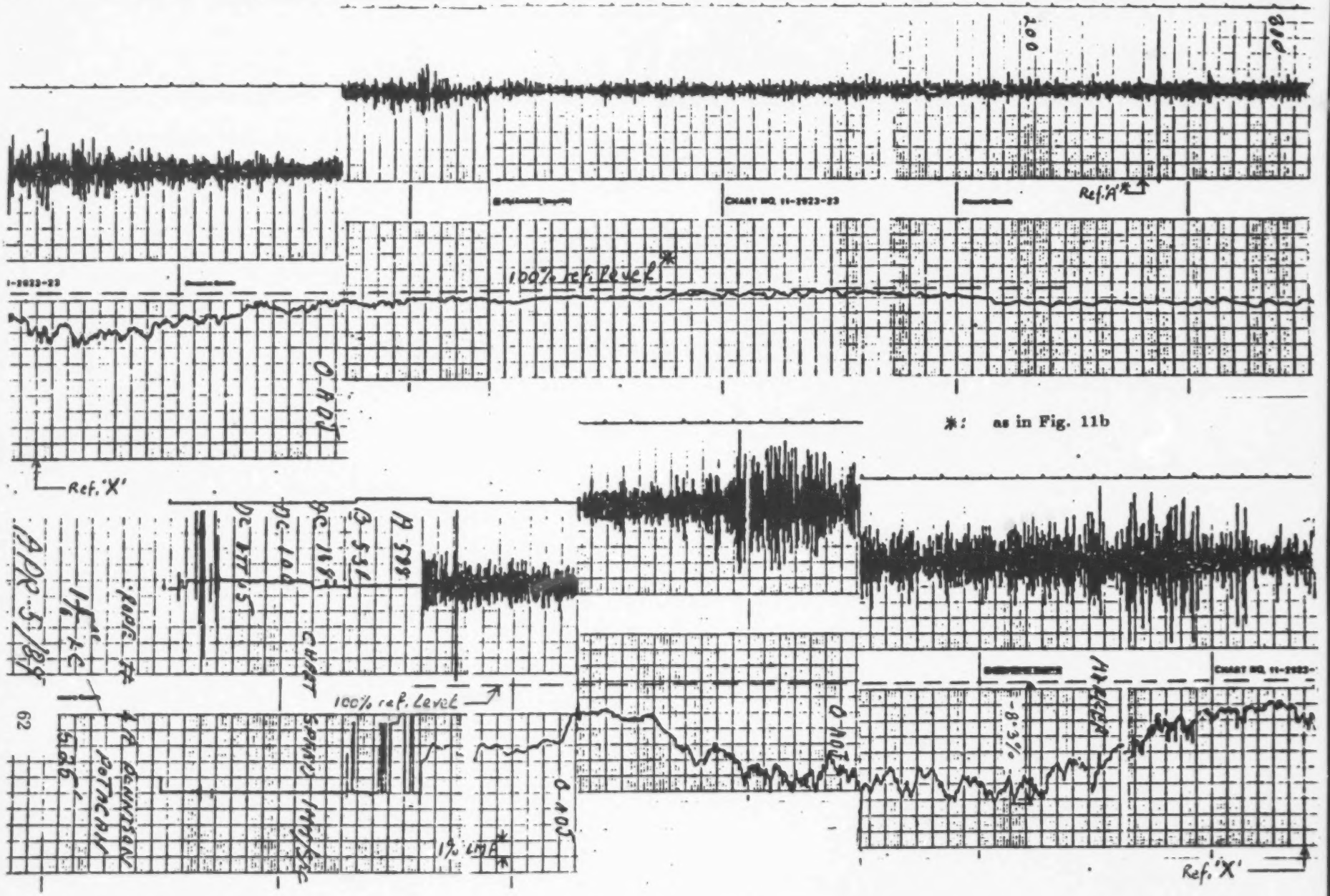


Fig. 12a — Rotescograph shop-floor test of 1987-1988 rope (2,350 ft tested); authors' analysis of 5.4.89 test (i.e., of Figures 11a and 11b), with realignment and resplicing

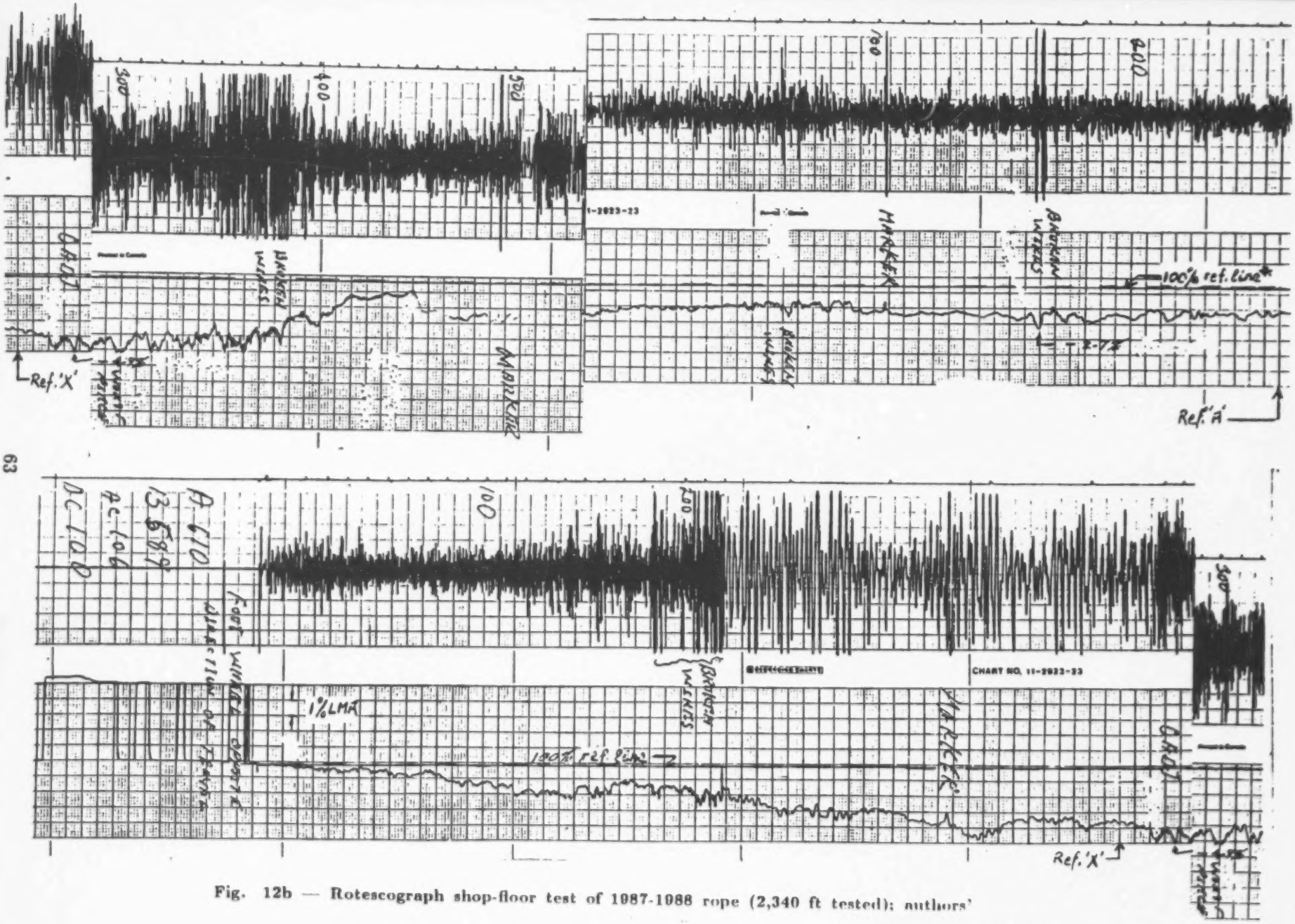


Fig. 12b — Rotescograph shop-floor test of 1987-1988 rope (2,340 ft tested); authors' analysis of 10.4.89 test (i.e., of Figures 11c and 11d) with realignment and resplicing

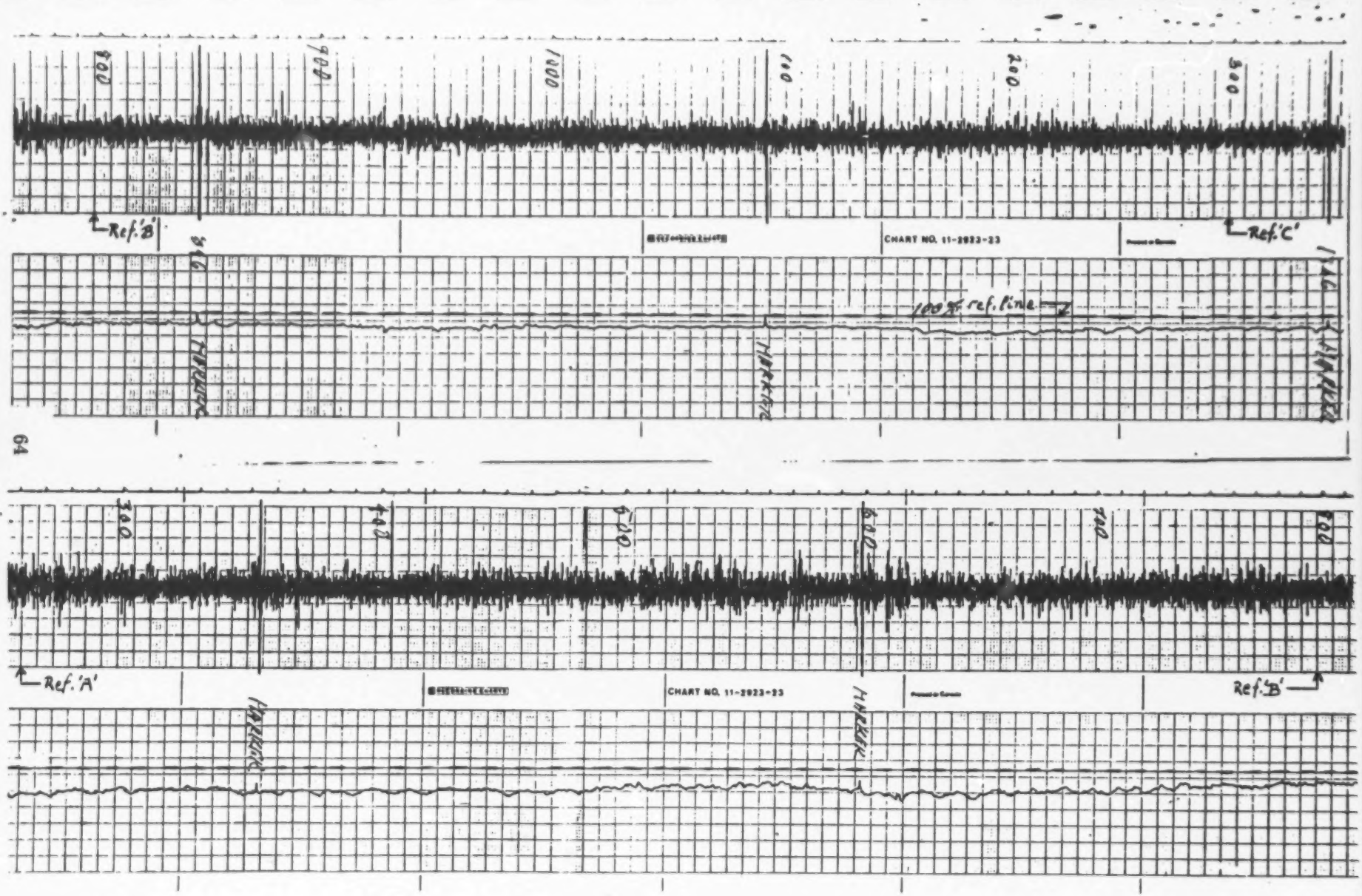


Fig. 12b (continued) — Rotescograph shop-floor test of 1987-1988 rope (2,340 ft tested);

authors' analysis of 10.4.89 test (i.e., of Figures 11c and 11d), with realignment and resplic ing

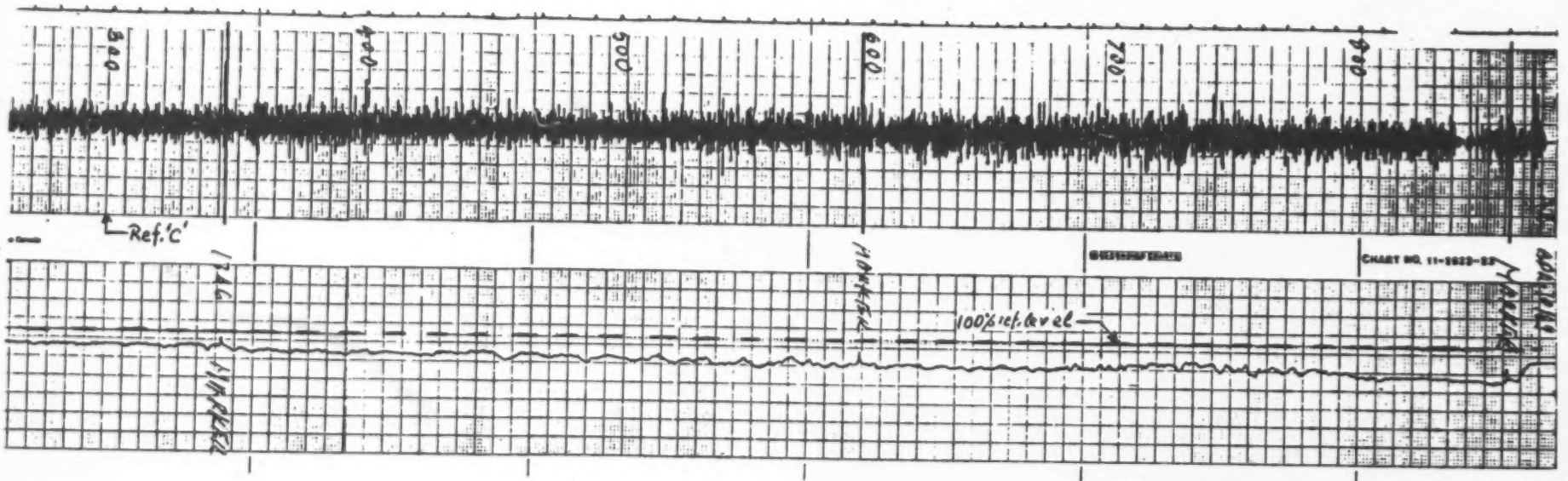


Fig. 12b (continued) — Rotescograph shop-floor test of 1987-1988 rope (2,340 ft tested);

authors' analysis of 10.4.89 test (i.e., of Figures 11c and 11d), with realignment and resplicing

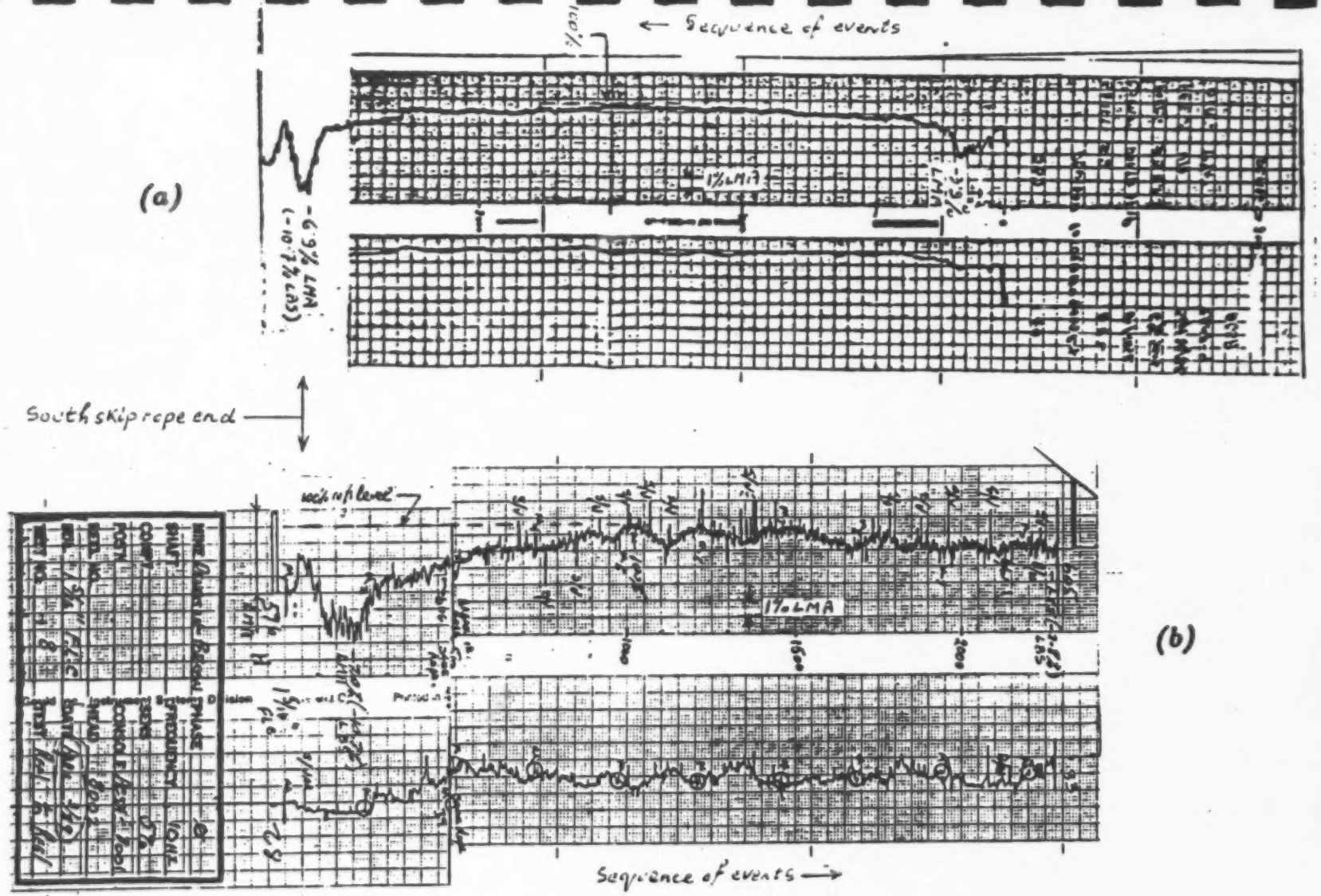


Fig. 13 — Rotesco AC tests, (a) 26.0.88 in situ (as Fig. 5b), and (b) 3.4.89 shop-floor (as Fig. 8c)

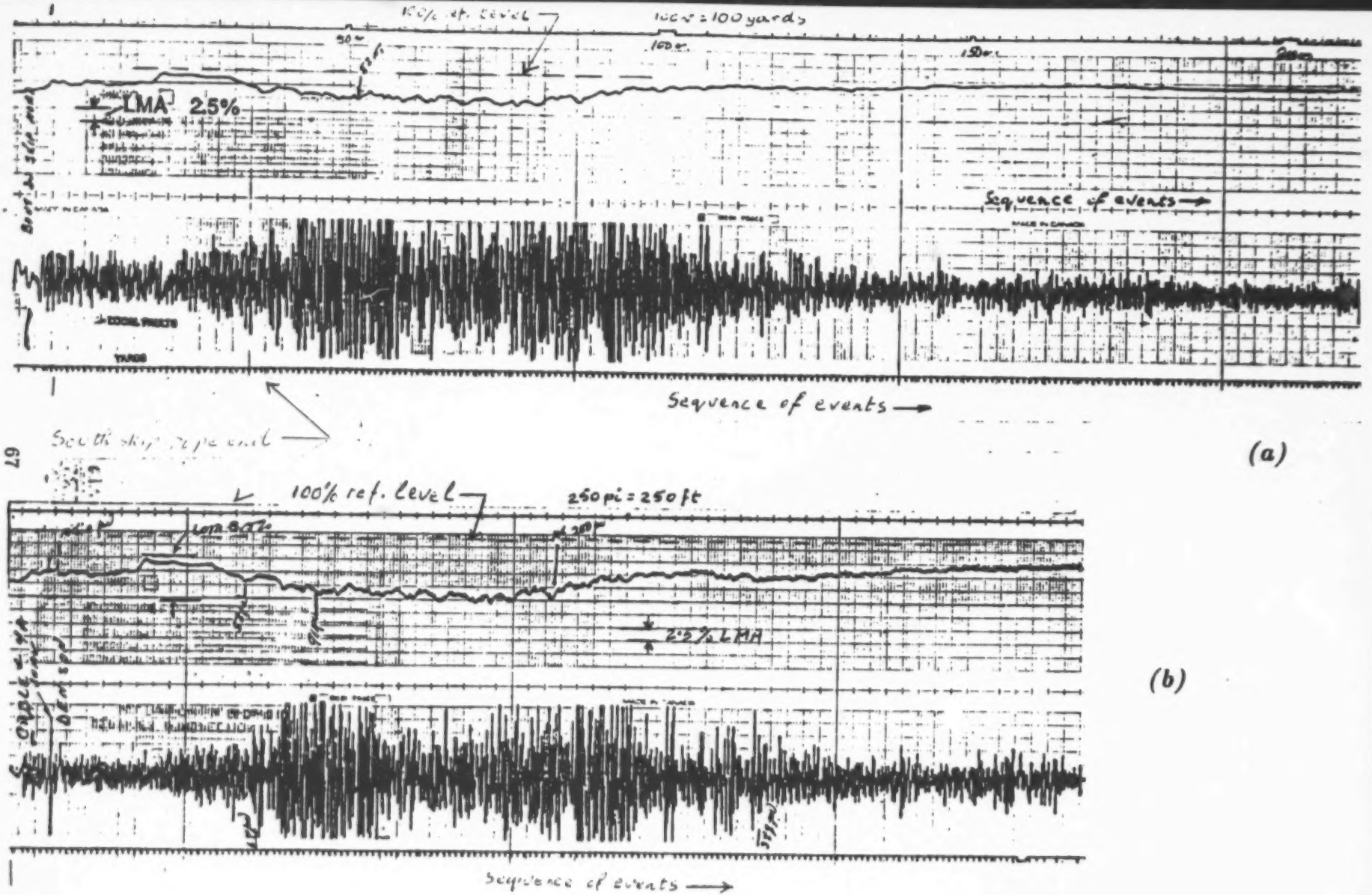
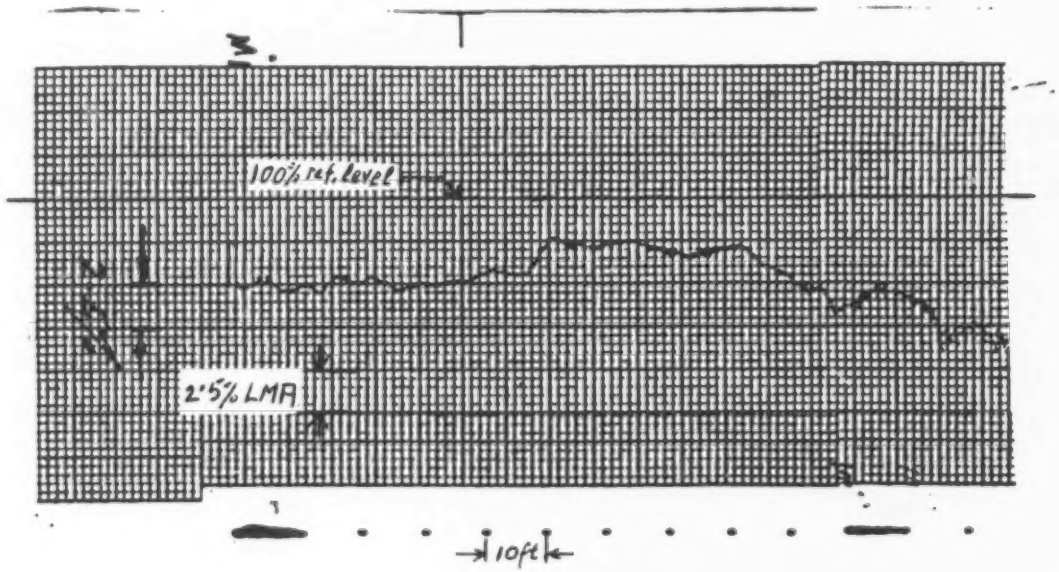


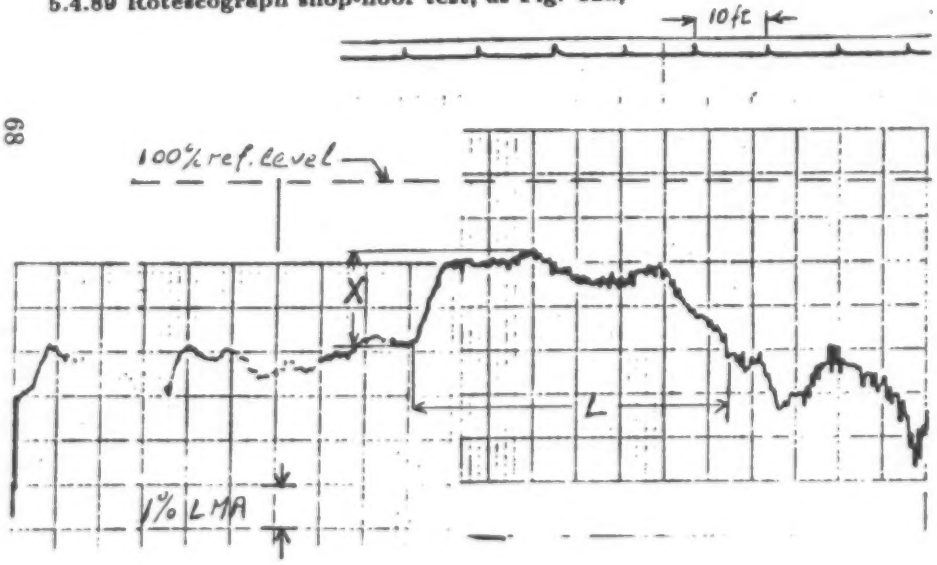
Fig. 14 — Magnograph tests of South skip rope end, (a) 19.10.88 in situ (as Fig. 3b), and (b) 4.4.89 shop-floor (as Fig. 9b)

(c) 4.4.89 LMA-250 shop-floor test, as Fig. 10,



(a)

5.4.89 Rotescograph shop-floor test, as Fig. 12a,



(b) 4.4.89 Magnograph shop-floor test, as Fig. 9a,

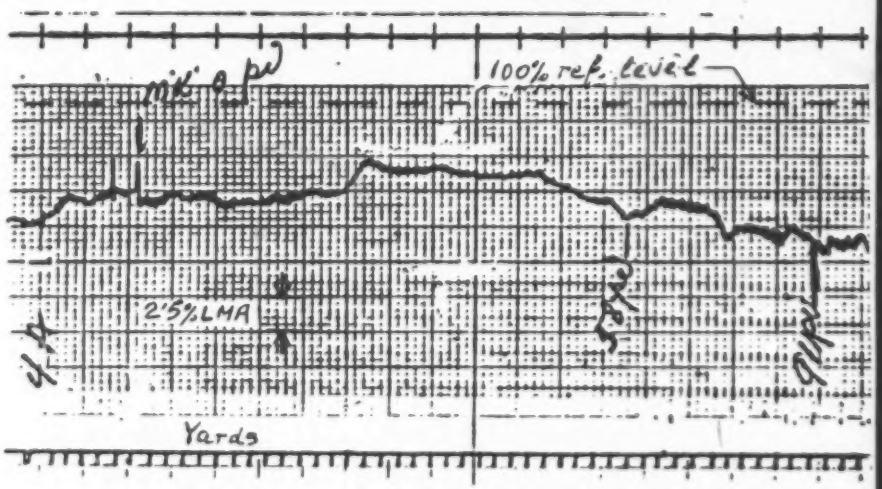
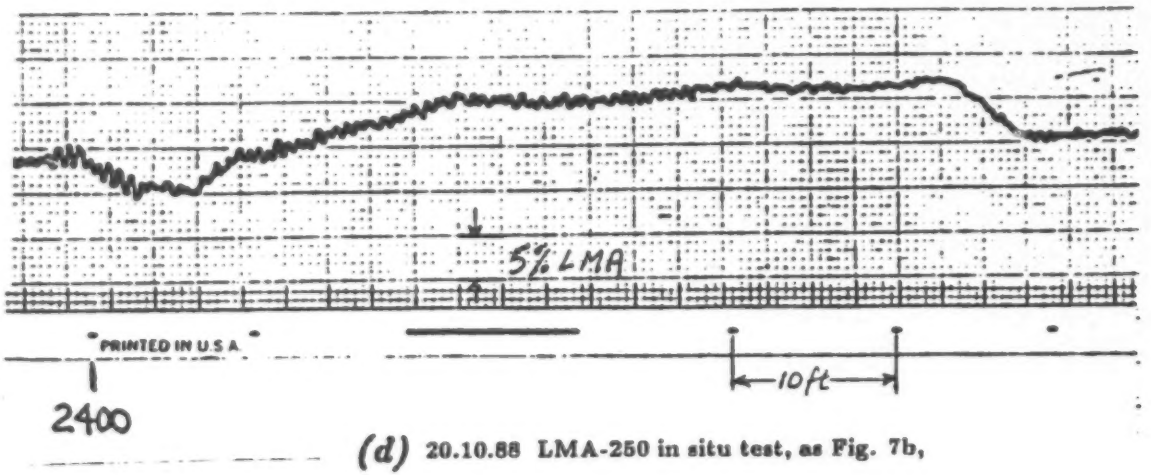


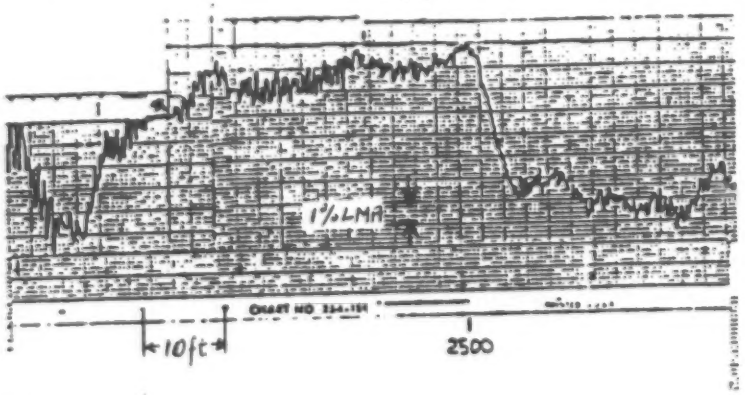
Fig. 15 — Rotescograph, LMA-250, and Magnograph tests of characteristic feature in South skip rope end,

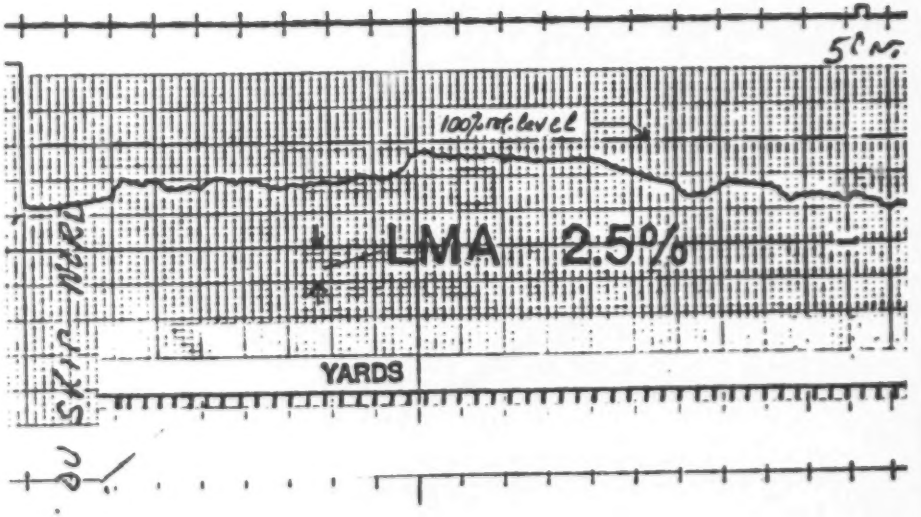


(d) **20.10.88 LMA-250 in situ test, as Fig. 7b,**

Sequence of events →

(e) **20.10.88 LMA-250 in situ test, as Fig. 7d,**





(f) **19.10.88 Magnograph in situ test, as Fig. 3b**

Fig. 15 (continued) — Rotescograph, LMA-250, and Magnograph tests of characteristic feature in South skip rope end

Fig. 16 — General view of coned samples

Fig. 17 — General view of Tinius-Olsen tensile testing machine

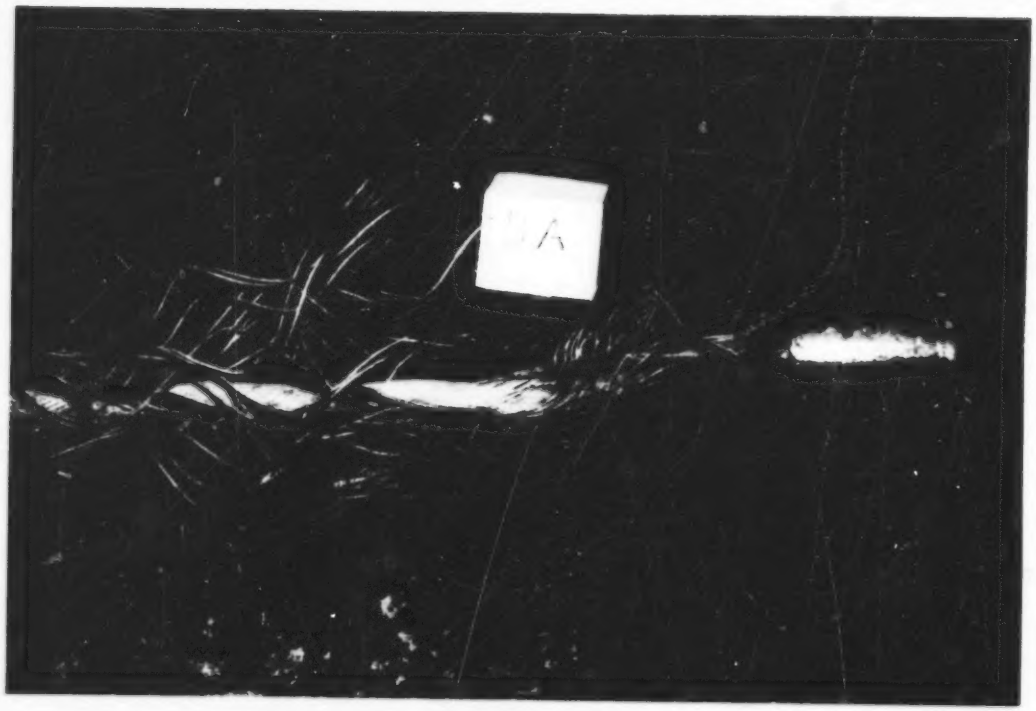


Fig. 18 — Different views of broken sample #4a

Fig. 18 (continued) — Different views of broken sample #4a

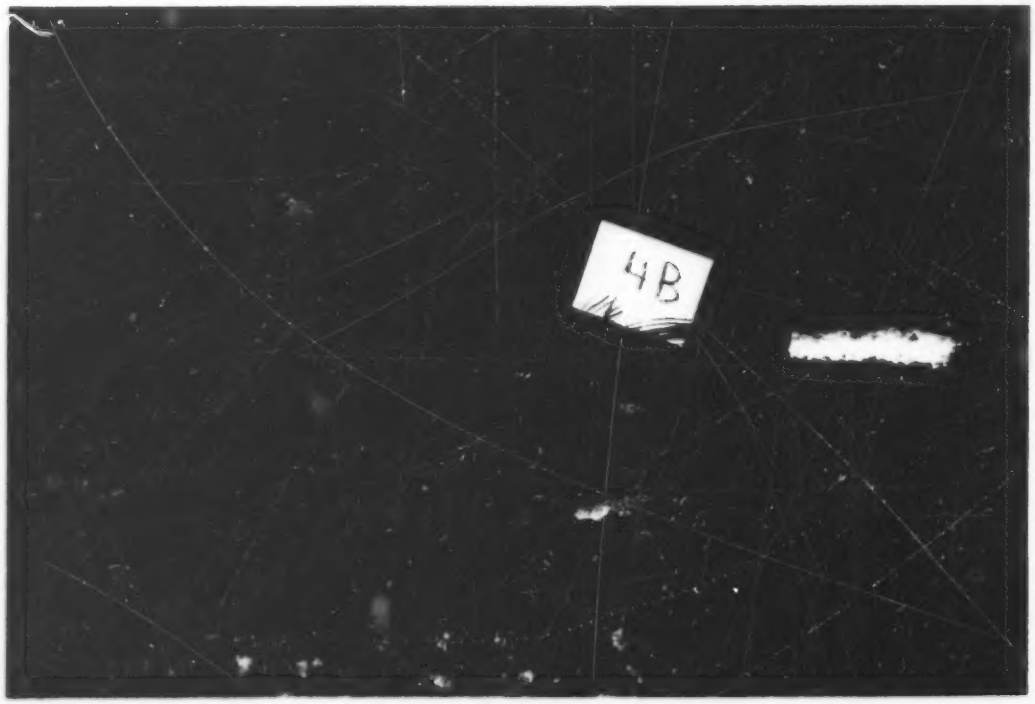


Fig. 19 — Different views of broken sample #4b

Fig. 10 (continued) — Different views of broken sample #4b

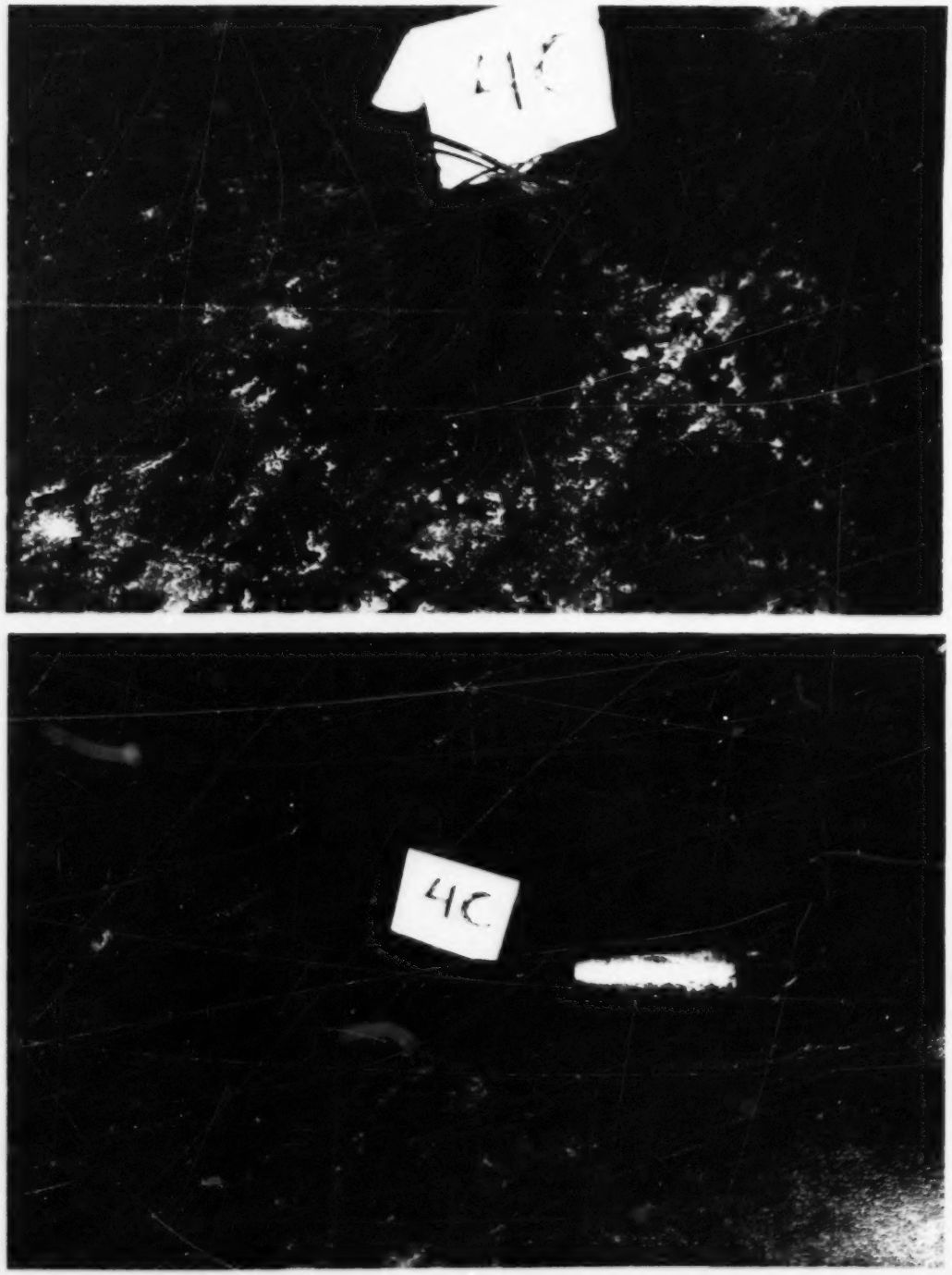


Fig. 20 — Different views of broken sample #4c

Fig. 21 — Broken sample #4d

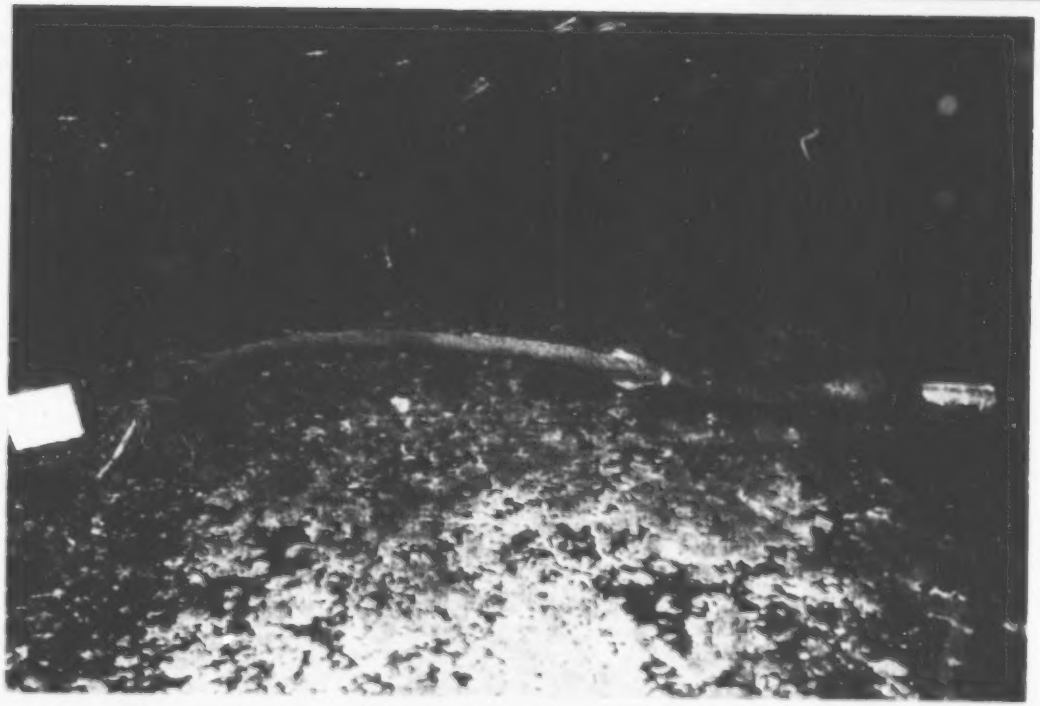


Fig. 22 — Different views of broken sample #4e

Fig. 22 (continued) — Different views of broken sample #4e